US009288687B2

(12) **United States Patent**
Bassiri et al.

(10) **Patent No.: US 9,288,687 B2**
(45) **Date of Patent: Mar. 15, 2016**

(54) **AUTOMATIC DETERMINATION OF COMPONENT TYPES AND LOCATIONS FOR WIRELESS NETWORK DESIGN**

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(72) Inventors: **Masoud Bassiri**, Singapore (SG); **Tooraj Forughian**, Singapore (SG); **Duncan Karl Gordon Campbell**, Singapore (SG); **Hua Zhang**, Singapore (SG)

(73) Assignee: **CONSISTEL PTE LTD**, Singapore (SG)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/788,634**

(22) Filed: **Jun. 30, 2015**

(65) **Prior Publication Data**

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Related U.S. Application Data

(63) Continuation of application No. PCT/SG2013/000003, filed on Jan. 3, 2013.

(51) **Int. Cl.**

H04W 24/00	(2009.01)
H04W 16/20	(2009.01)
H04W 4/02	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 16/20*** (2013.01); ***H04W 4/02*** (2013.01)

(58) **Field of Classification Search**

CPC G06F 17/509; G06F 2217/04; G06F 2217/06; G06Q 10/087; H04L 12/2602; H04L 41/06; H04L 41/12; H04L 41/22; H04L 41/5003; H04L 43/00; H04L 43/0823; H04L 43/0847; H04L 43/0852; H04L 43/0864

See application file for complete search history.

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2013/0183961	A1 *	7/2013	Bassiri	H04W 16/20 455/423

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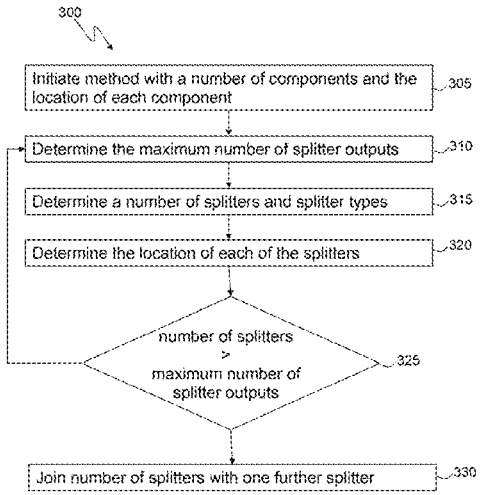
* cited by examiner

Primary Examiner — Kashif Siddiqui
(74) *Attorney, Agent, or Firm* — Beyer Law Group LLP

(57) **ABSTRACT**

A computer implemented method and system for determining component types and locations in a network design. The method includes automatically determining component types and locations according to a riser location as an entry point and antenna locations as a plurality of end points. The automatically determining component types and locations includes determining, by a processor of the computer, a first set of component types and locations according to a tree topology, according to the entry point and the plurality of end points, determining, by the processor, a second set of component types and locations according to a hybrid topology, according to the entry point and the plurality of end points, and determining, by the processor, one of the first set of component types and locations and the second set of component types and locations.

23 Claims, 21 Drawing Sheets



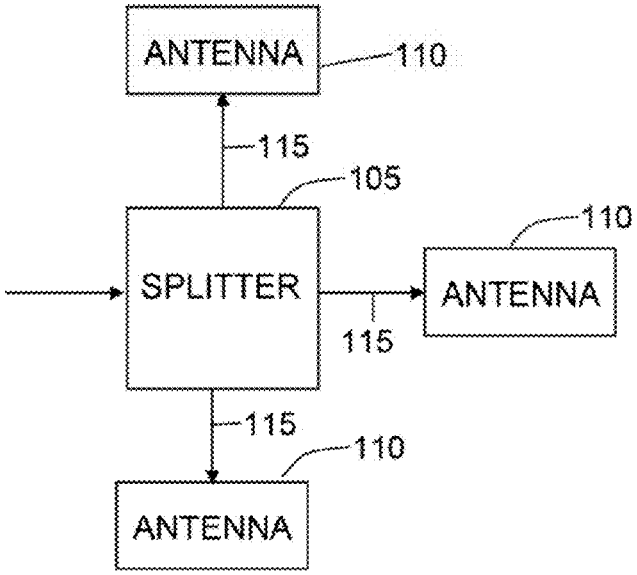


FIG. 1a

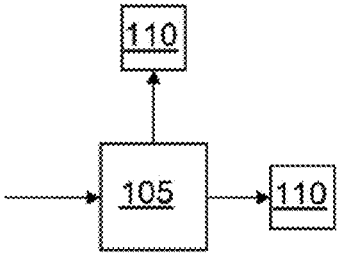


FIG. 1b

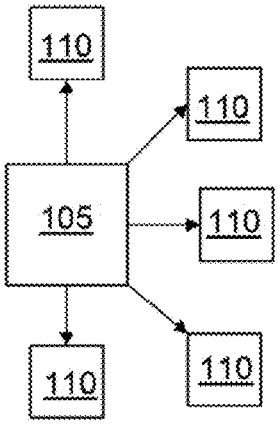


FIG. 1c

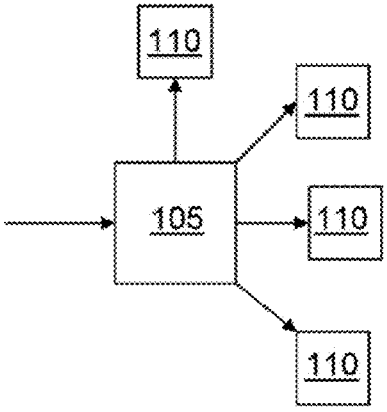


FIG. 1d

(PRIOR ART)

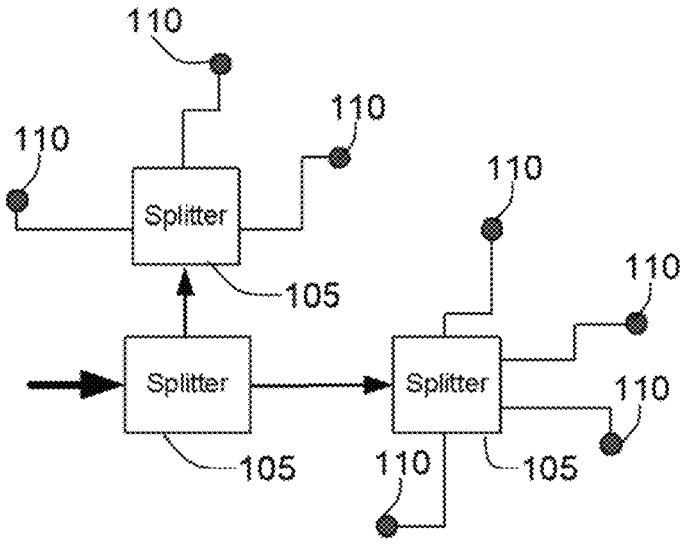


FIG 2a

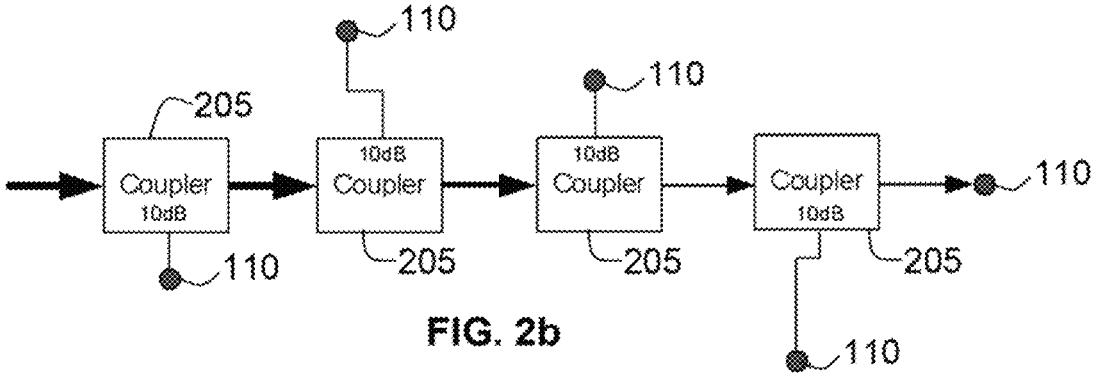


FIG. 2b

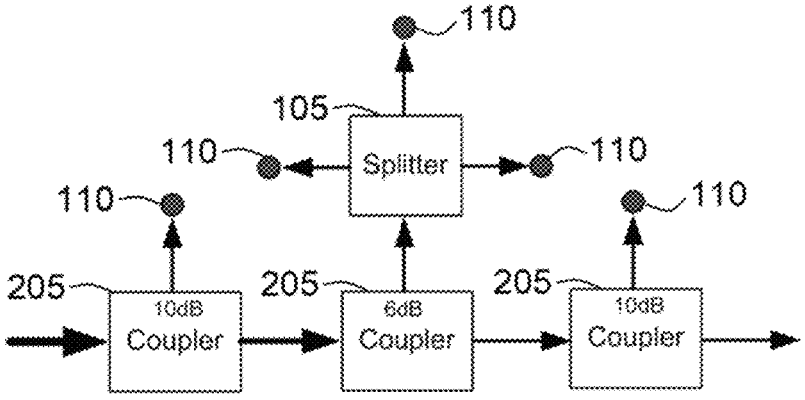


FIG. 2c

(PRIOR ART)

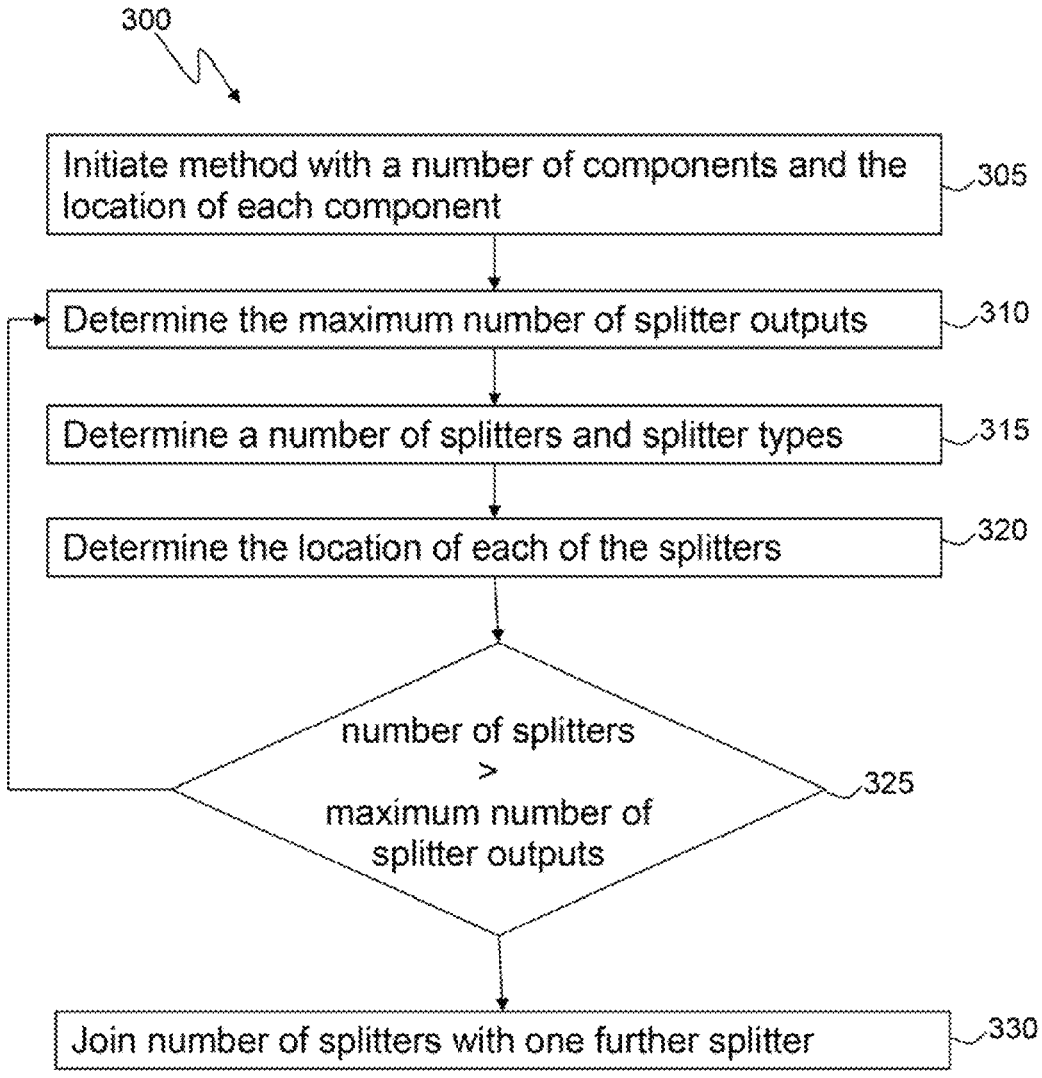

300
Initiate method with a number of components and the location of each component
305
Determine the maximum number of splitter outputs
310
Determine a number of splitters and splitter types
315
Determine the location of each of the splitters
320
number of splitters > maximum number of splitter outputs
325
Join number of splitters with one further splitter
330

FIG. 3

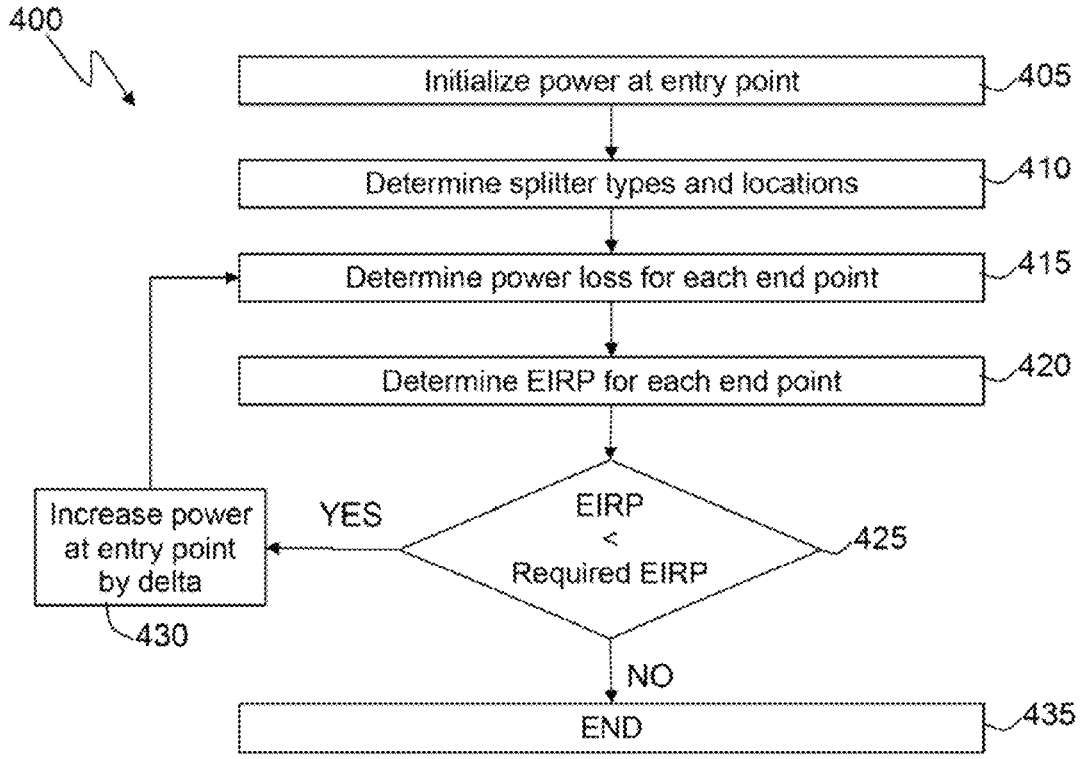

400
Initialize power at entry point
405
Determine splitter types and locations
410
Determine power loss for each end point
415
Determine EIRP for each end point
420
EIRP
<
Required EIRP
425
YES
Increase power at entry point by delta
430
NO
END
435

FIG. 4

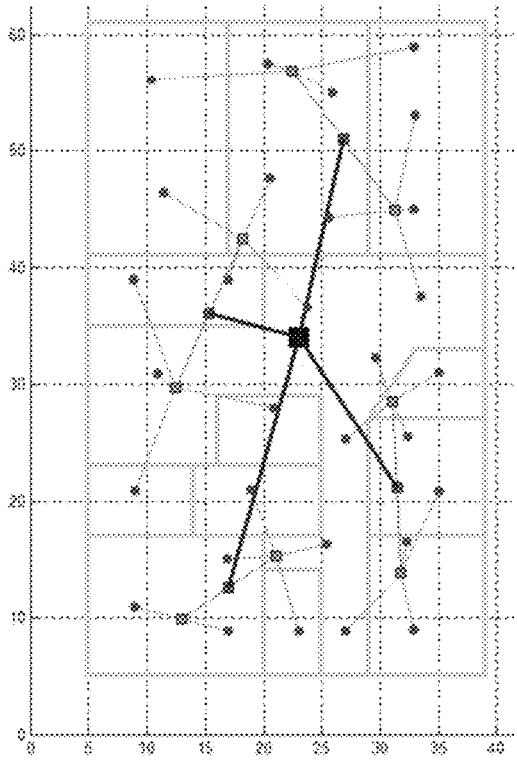


FIG. 5a

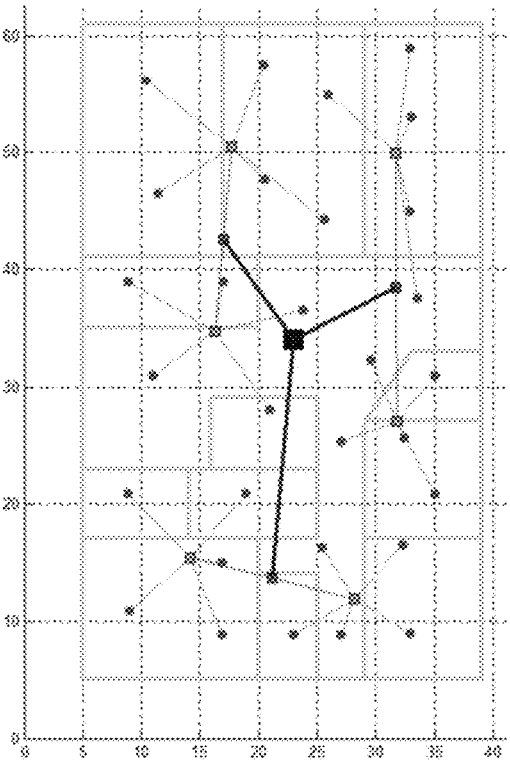


FIG. 5b

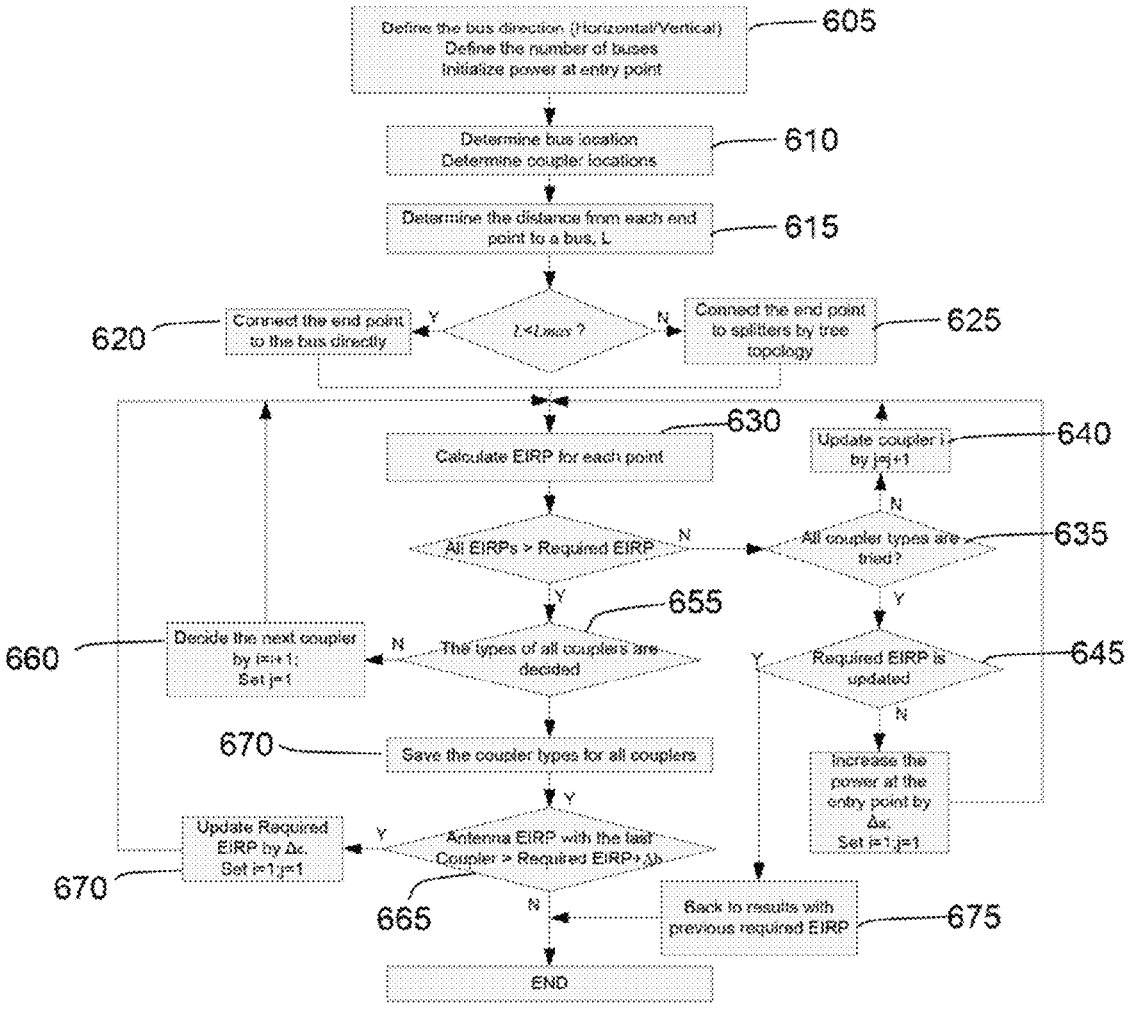

Define the bus direction (Horizontal/Vertical)
Define the number of buses
Initialize power at entry point
605
Determine bus location
Determine coupler locations
610
Determine the distance from each end point to a bus, L
615
620
Connect the end point to the bus directly
Y
L<Lmax ?
N
Connect the end point to splitters by tree topology
625
630
Calculate EIRP for each point
640
Update coupler i by j=j+1
All EIRPs > Required EIRP
N
All coupler types are tried ?
635
Y
655
660
Decide the next coupler by i=i+1; Set j=1
N
The types of all couplers are decided
Y
Required EIRP is updated
645
N
670
Save the coupler types for all couplers
Increase the power at the entry point by Δx; Set i=1,j=1
Update Required EIRP by Δc; Set i=1,j=1
Y
Antenna EIRP with the last Coupler > Required EIRP+Δb
670
665
N
Back to results with previous required EIRP
675
END

FIG. 6

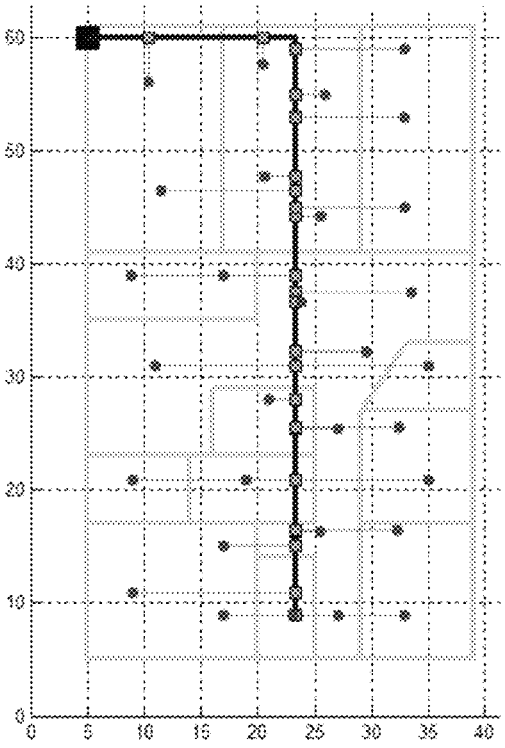

0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40

FIG. 7a

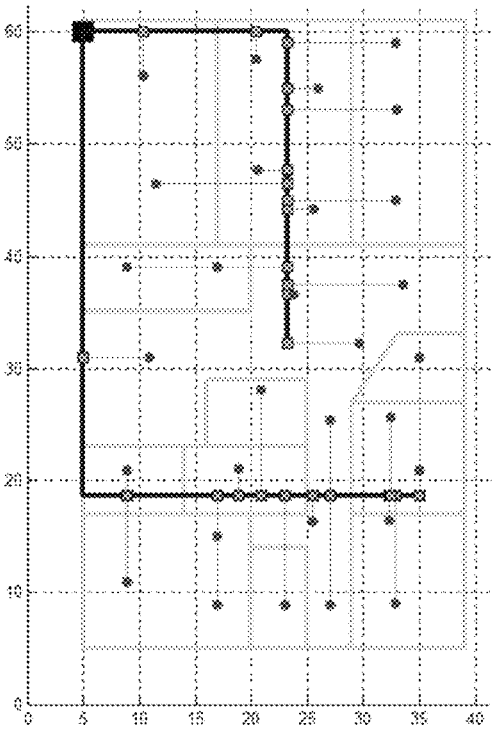

0
10
20
30
40
50
60
0
5
10
15
20
25
30
35
40

FIG. 7b

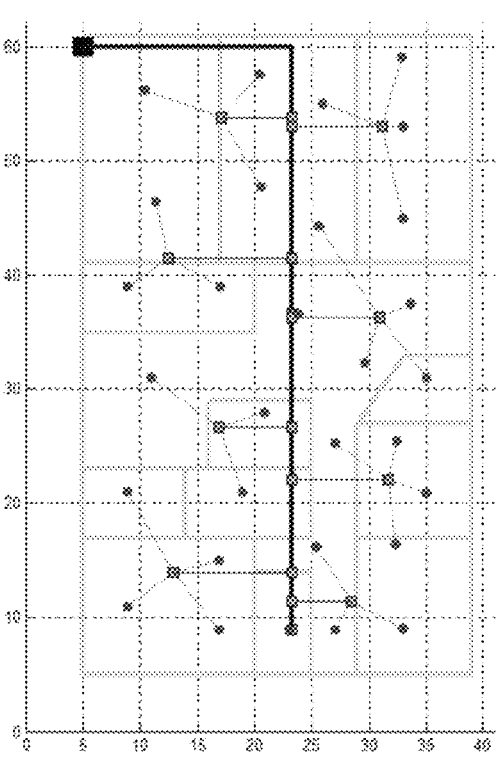


FIG. 8a

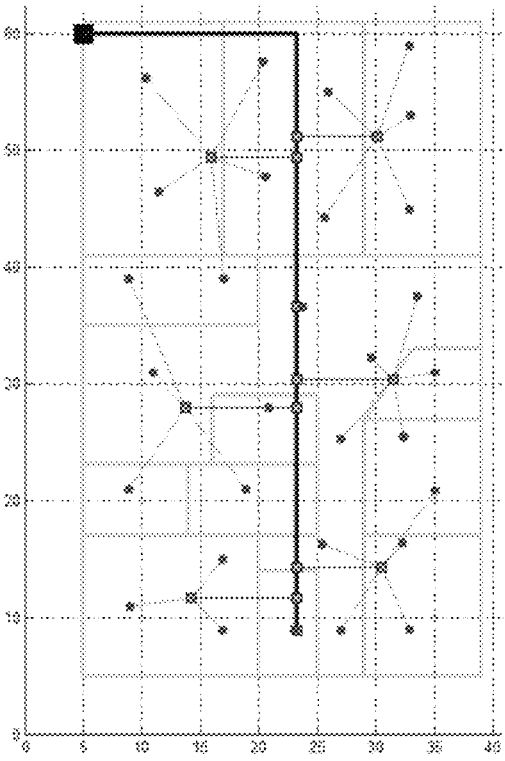


FIG. 8b

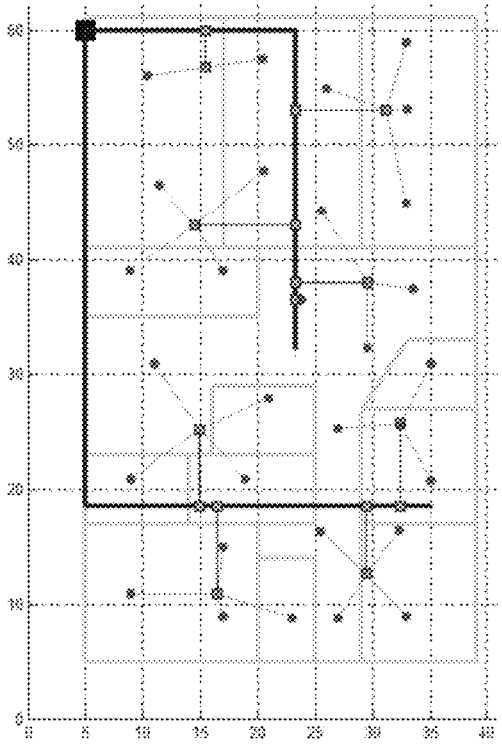


FIG. 9a

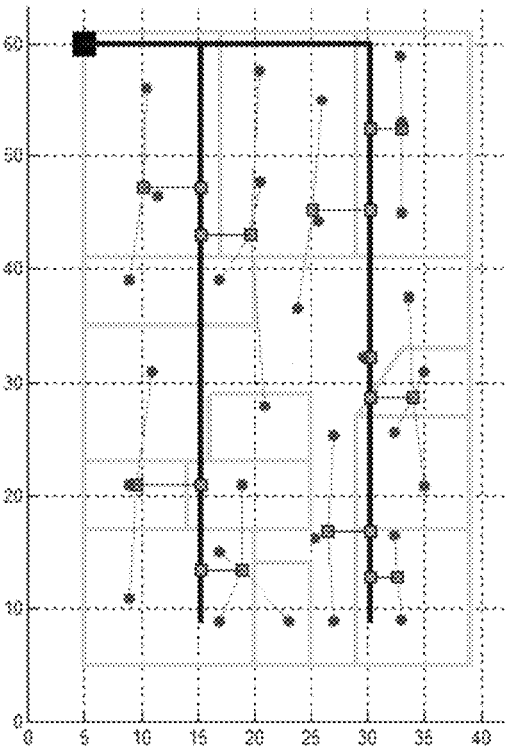


FIG. 9b

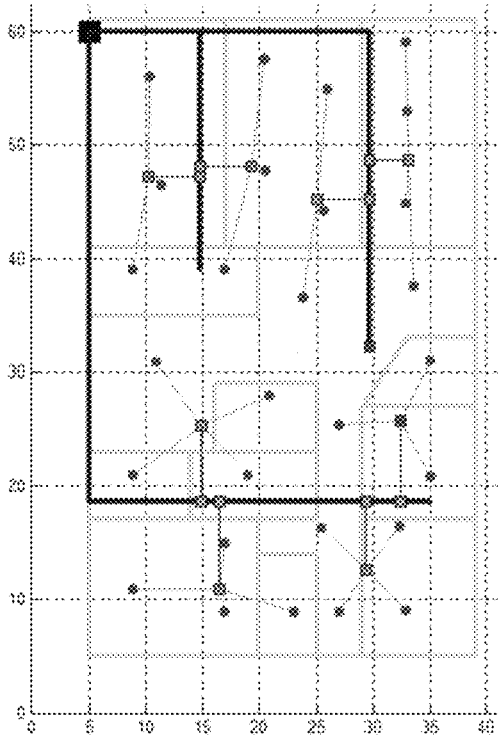


FIG. 9c

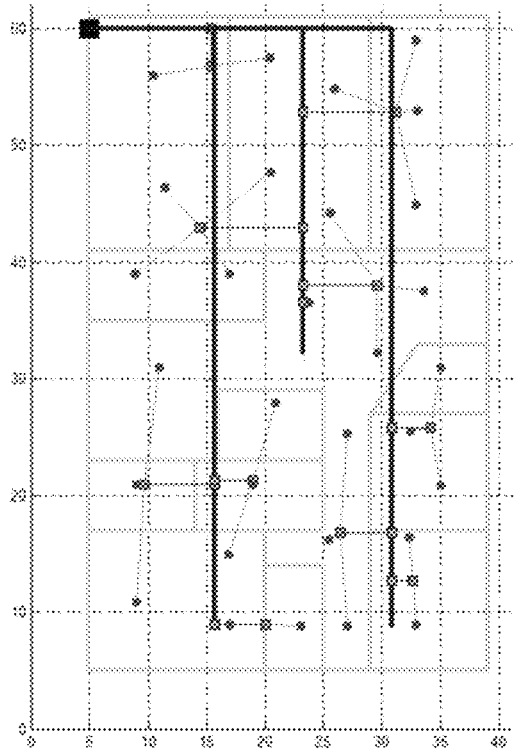


FIG. 9d

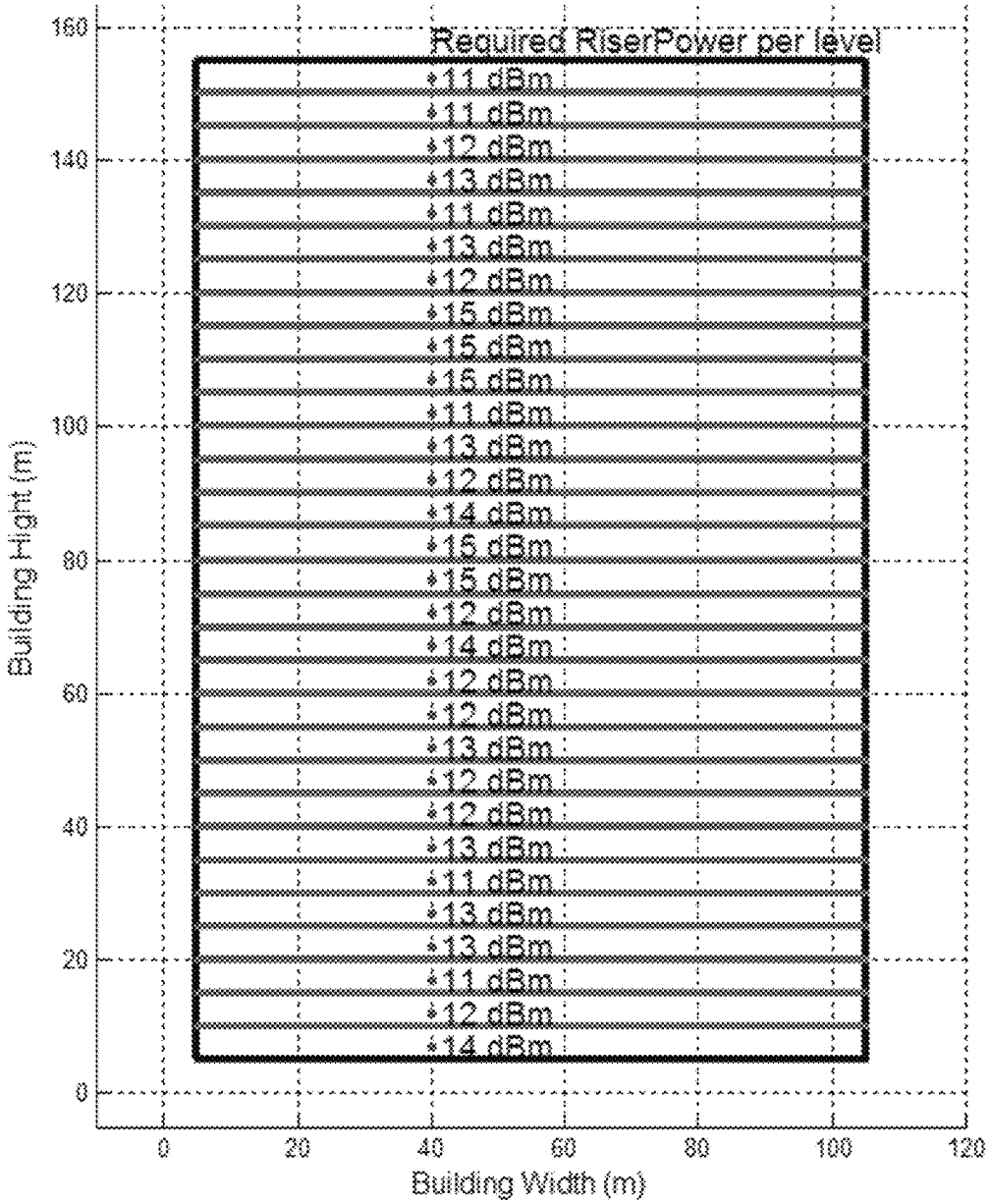

Required RiserPower per level
11 dBm
11 dBm
12 dBm
13 dBm
11 dBm
13 dBm
12 dBm
15 dBm
15 dBm
15 dBm
11 dBm
13 dBm
12 dBm
14 dBm
15 dBm
15 dBm
12 dBm
14 dBm
12 dBm
12 dBm
13 dBm
12 dBm
12 dBm
13 dBm
11 dBm
13 dBm
13 dBm
11 dBm
12 dBm
14 dBm
Building Hight (m)
0
20
40
60
80
100
120
140
160
Building Width (m)
0
20
40
60
80
100
120

FIG. 10

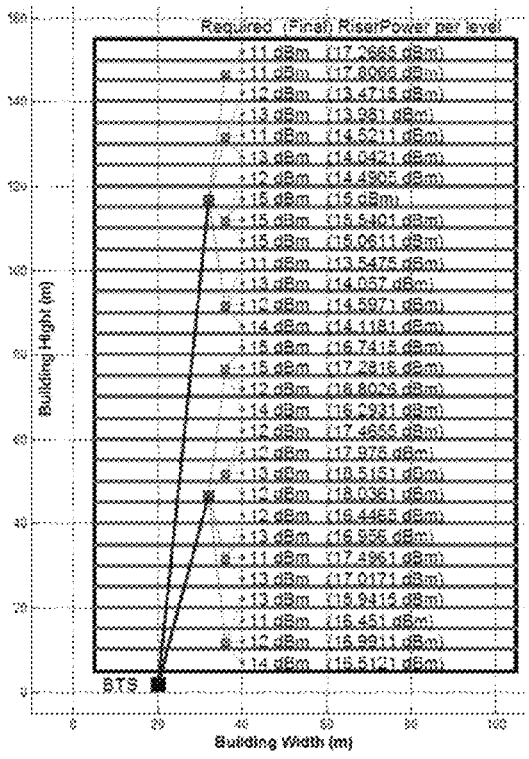


FIG. 11a

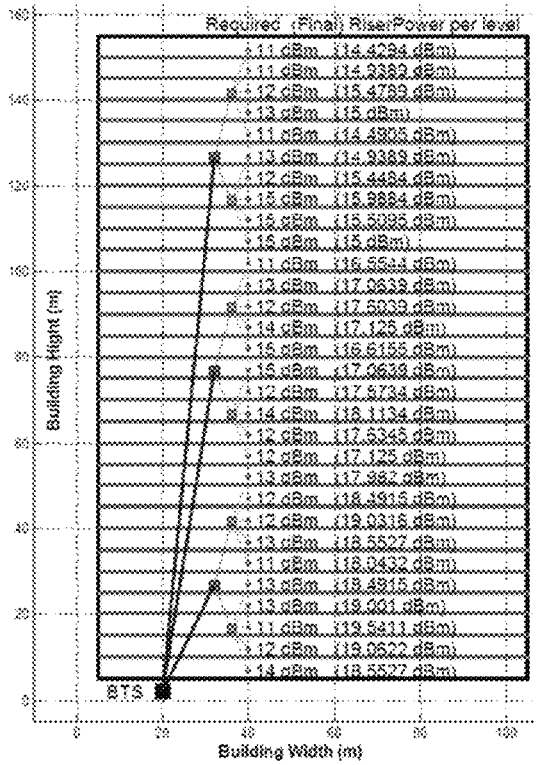


FIG. 11b

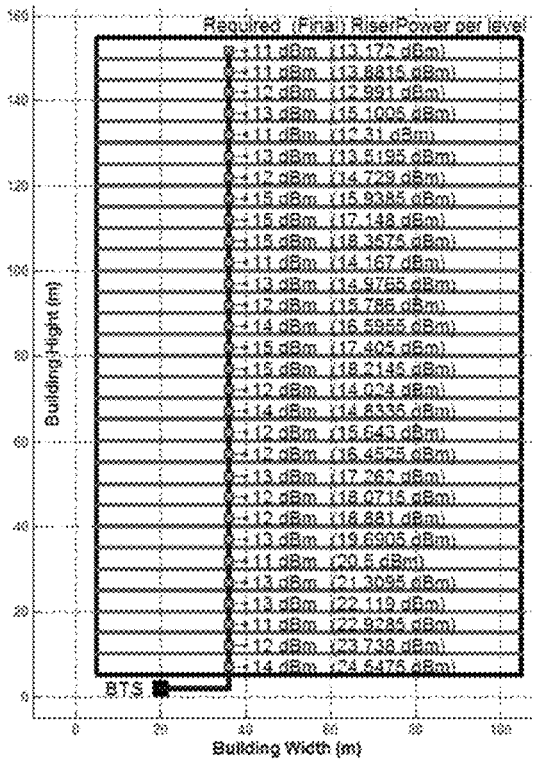


FIG. 12a

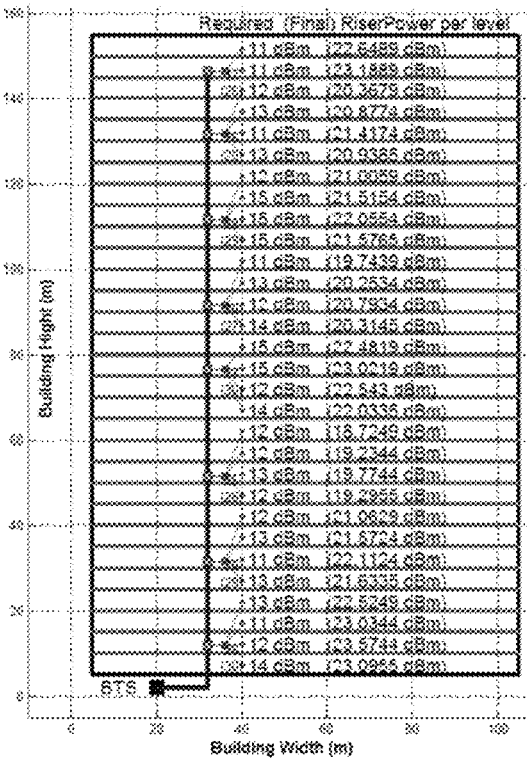


FIG. 12b

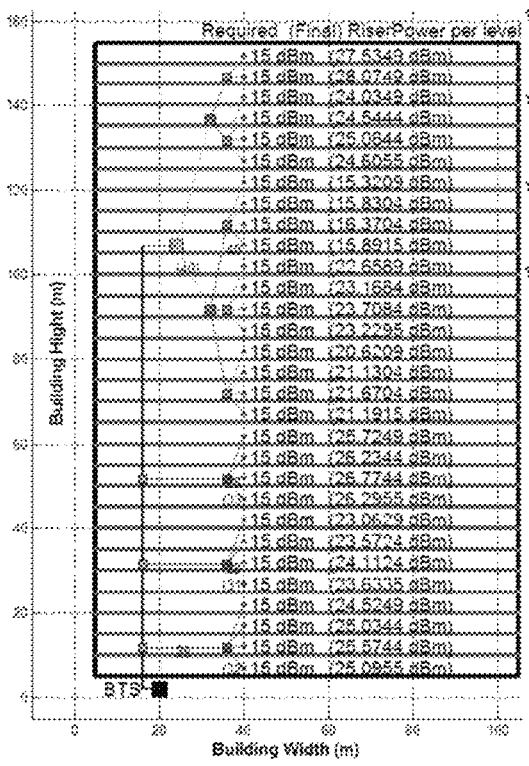


FIG. 13a

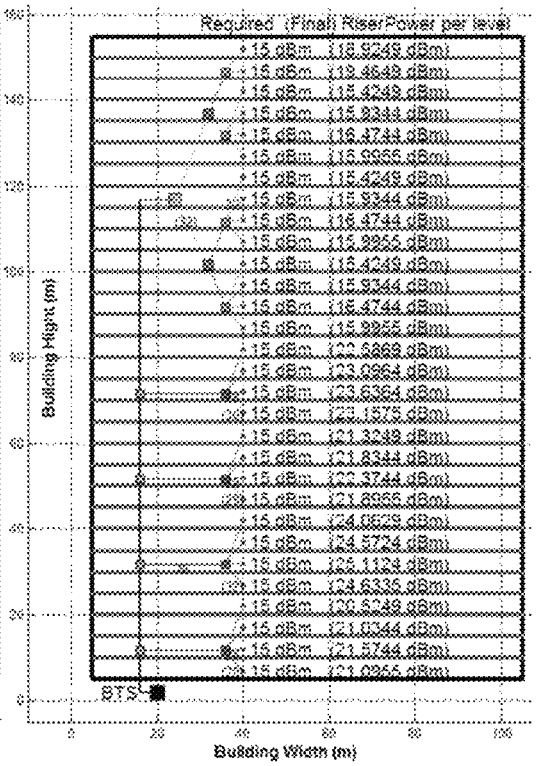


FIG. 13b

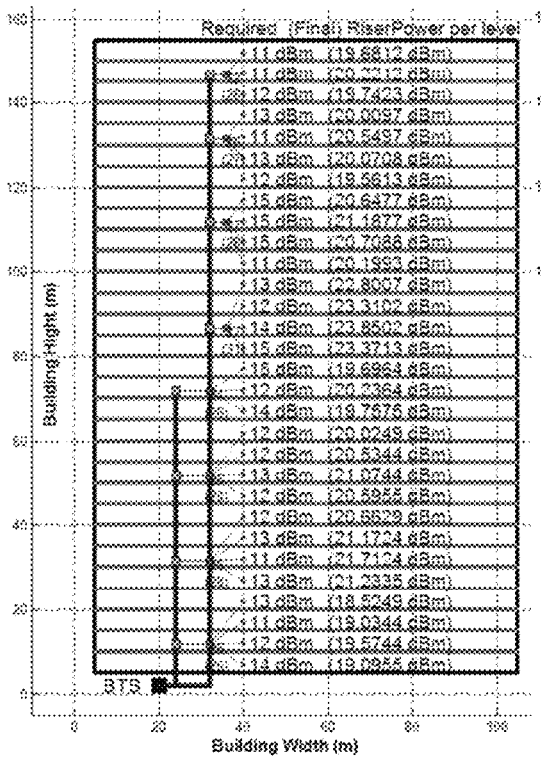


FIG. 14a

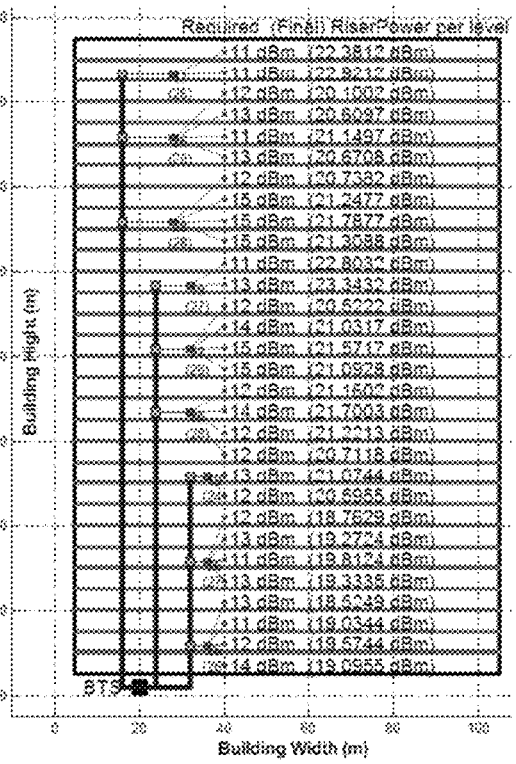


FIG. 14b

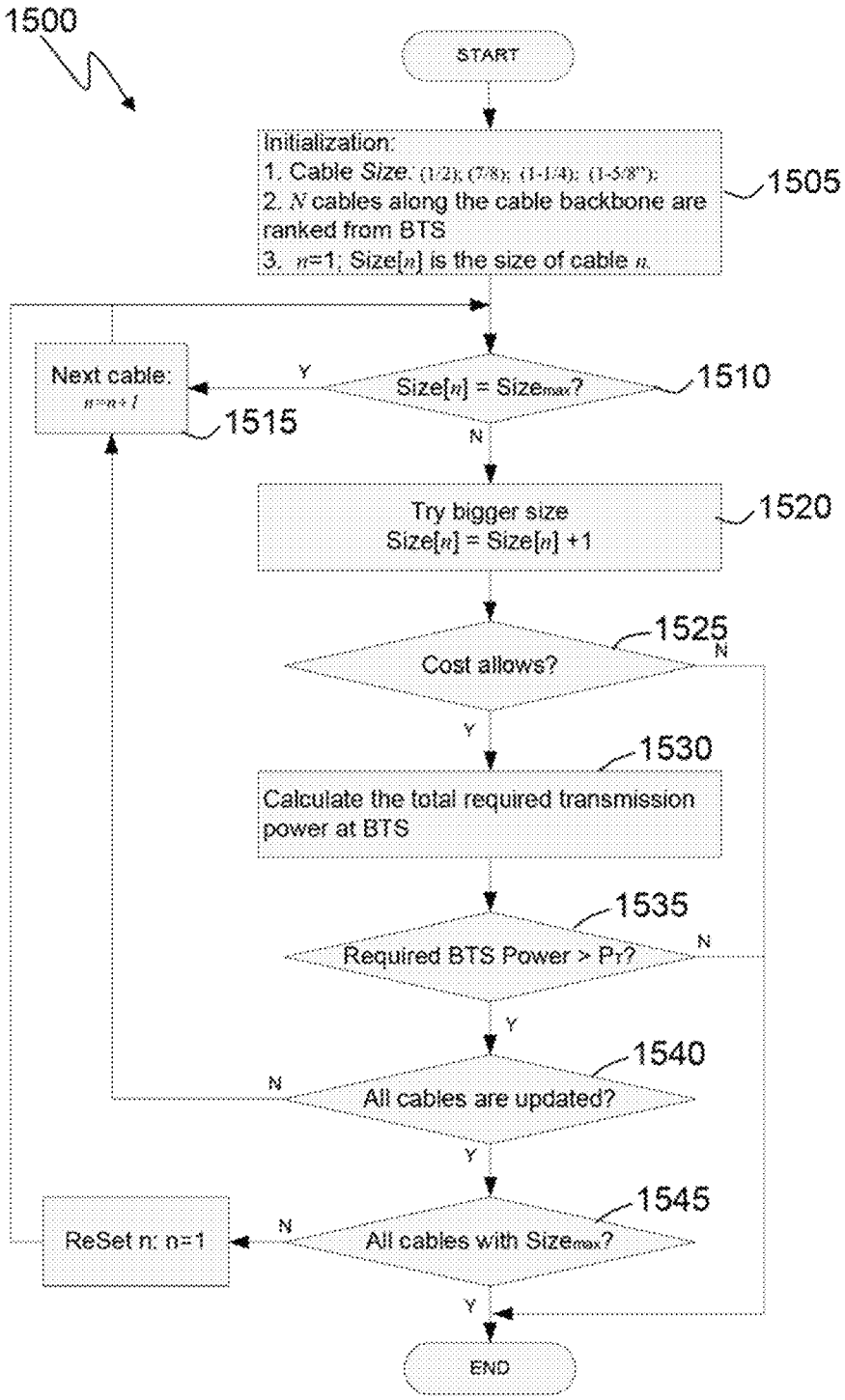

1500
START
Initialization:
1. Cable Size: (1/2); (7/8); (1-1/4); (1-5/8");
2. N cables along the cable backbone are ranked from BTS
3. n=1; Size[n] is the size of cable n.
1505
Size[n] = Size_max?
1510
Y
N
Next cable:
n=n+1
1515
Try bigger size
Size[n] = Size[n] +1
1520
Cost allows?
1525
N
Y
Calculate the total required transmission power at BTS
1530
Required BTS Power > P_T?
1535
N
Y
All cables are updated?
1540
N
Y
All cables with Size_max?
1545
N
ReSet n: n=1
Y
END

FIG. 15

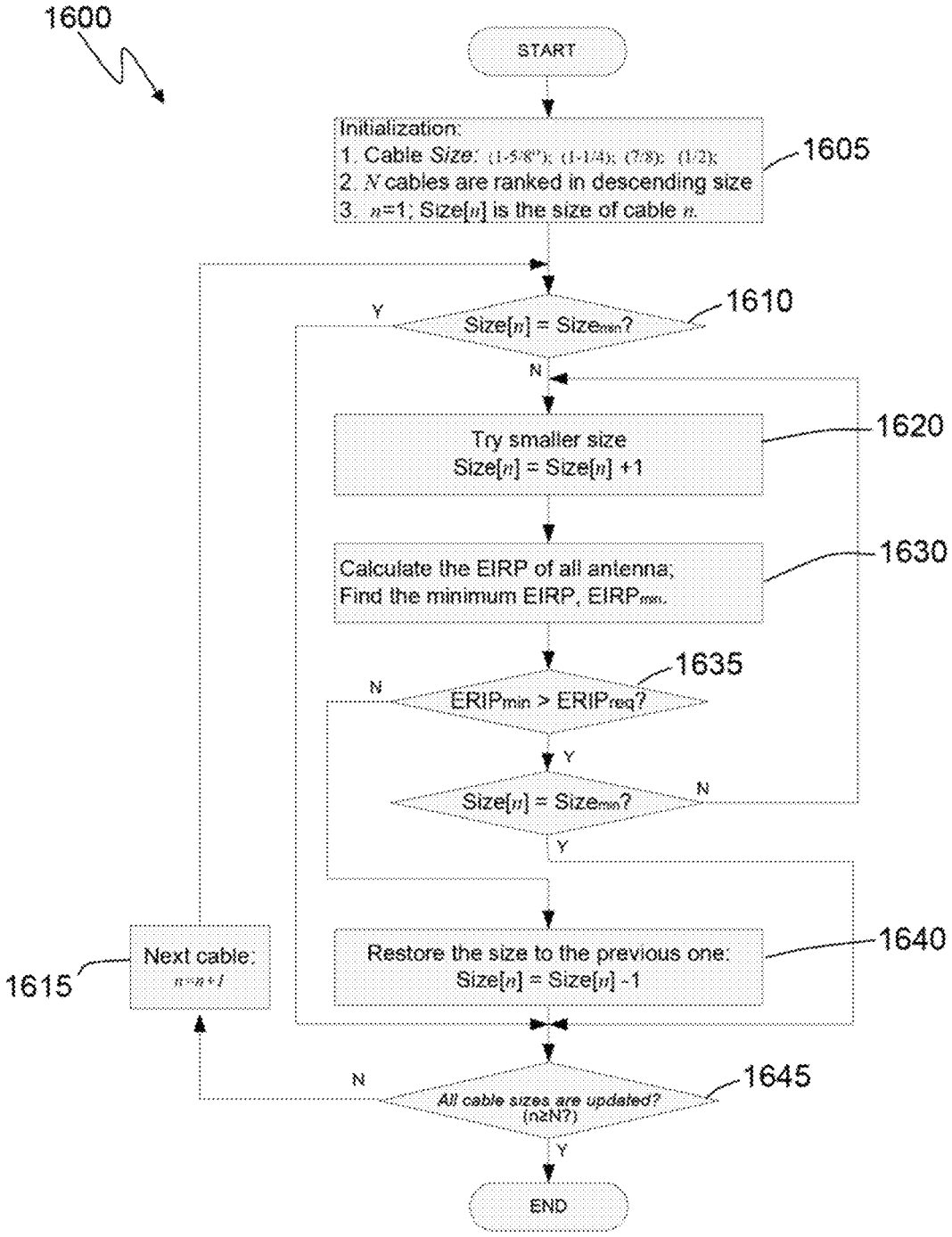

1600
START
Initialization:
1. Cable Size: (1-5/8"); (1-1/4); (7/8); (1/2);
2. N cables are ranked in descending size
3. n=1; Size[n] is the size of cable n.
1605
Size[n] = Size_min?
1610
Y
N
Try smaller size
Size[n] = Size[n] +1
1620
Calculate the EIRP of all antenna;
Find the minimum EIRP, EIRP_min.
1630
ERIP_min > ERIP_req?
1635
N
Y
Size[n] = Size_min?
N
Y
Next cable:
n=n+1
1615
Restore the size to the previous one:
Size[n] = Size[n] -1
1640
All cable sizes are updated?
(n≥N?)
1645
N
Y
END

FIG. 16

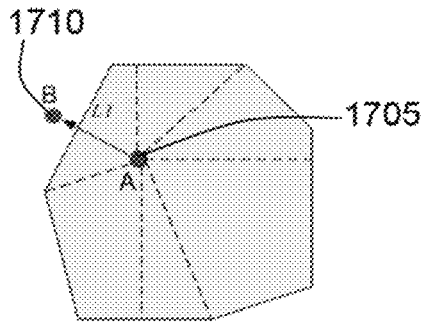


FIG. 17a

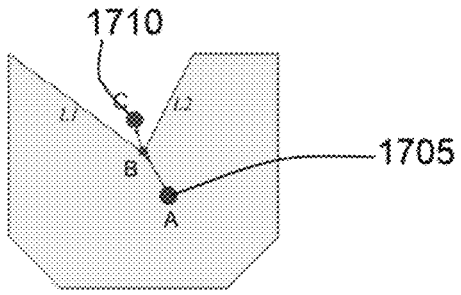


FIG. 17b

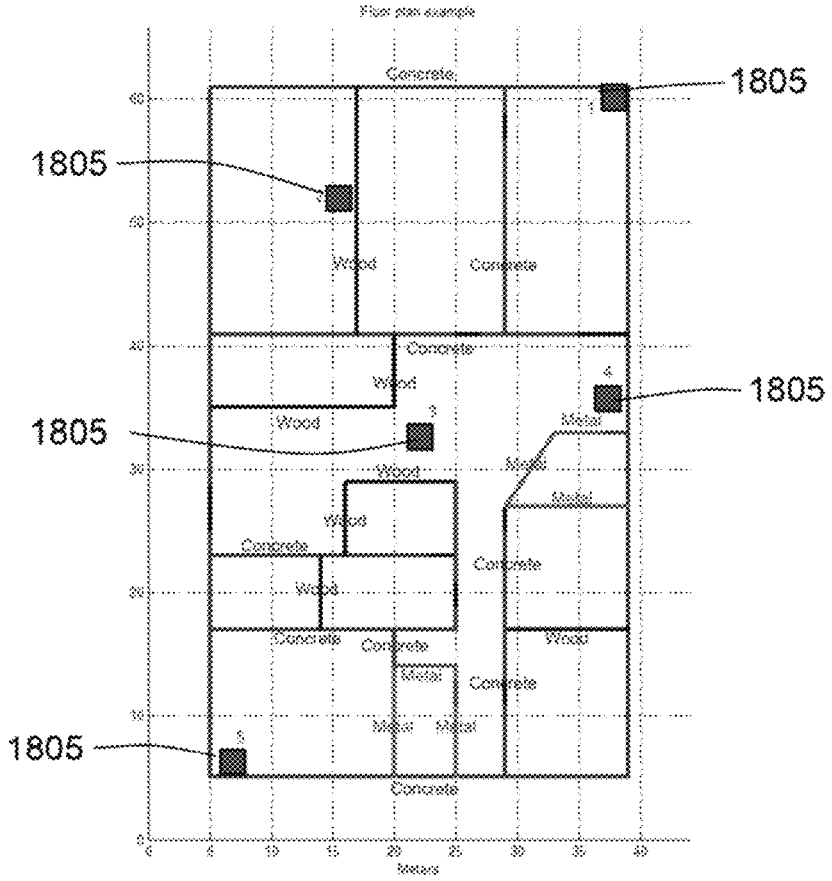

Floor plan example
Concrete
1805
1805
Wood
Concrete
Concrete
Wood
1805
Wood
1805
Metal
Wood
Metal
Wood
Metal
Concrete
Concrete
Wood
Concrete
Concrete
Wood
Metal
Concrete
Metal
Metal
1805
Concrete
Meters

FIG. 18

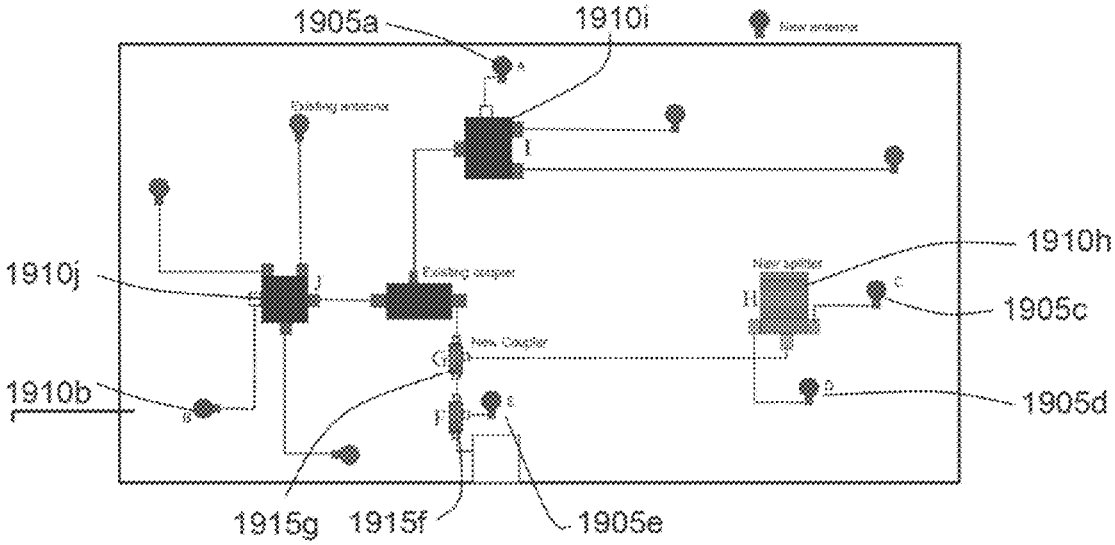

1905a
1910i
1910j
1910h
1905c
1910b
1905d
1915g
1915f
1905e

FIG. 19

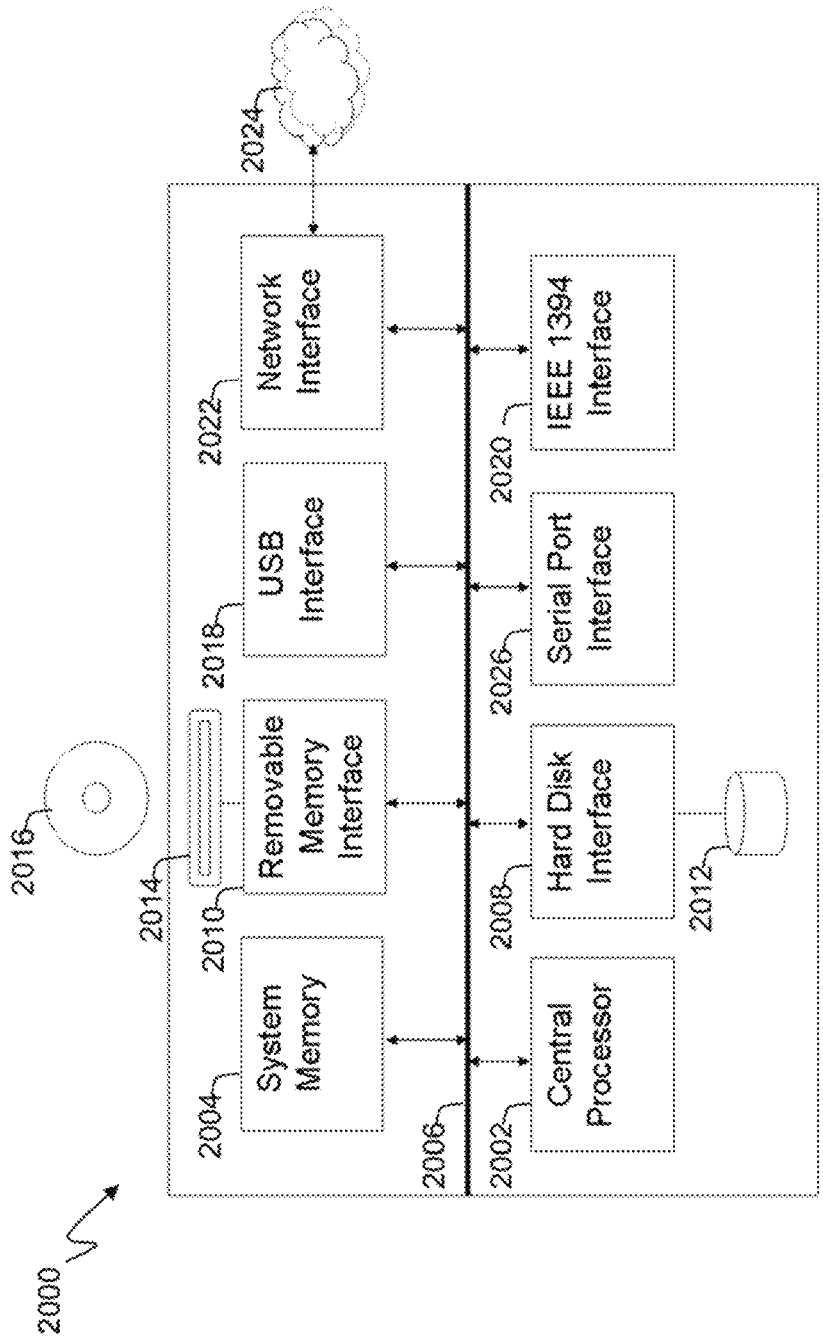

2000
2002
Central Processor
2004
System Memory
2006
2008
Hard Disk Interface
2010
Removable Memory Interface
2012
2014
2016
2018
USB Interface
2020
Serial Port Interface
2022
Network Interface
2024
IEEE 1394 Interface
2026

FIG. 20

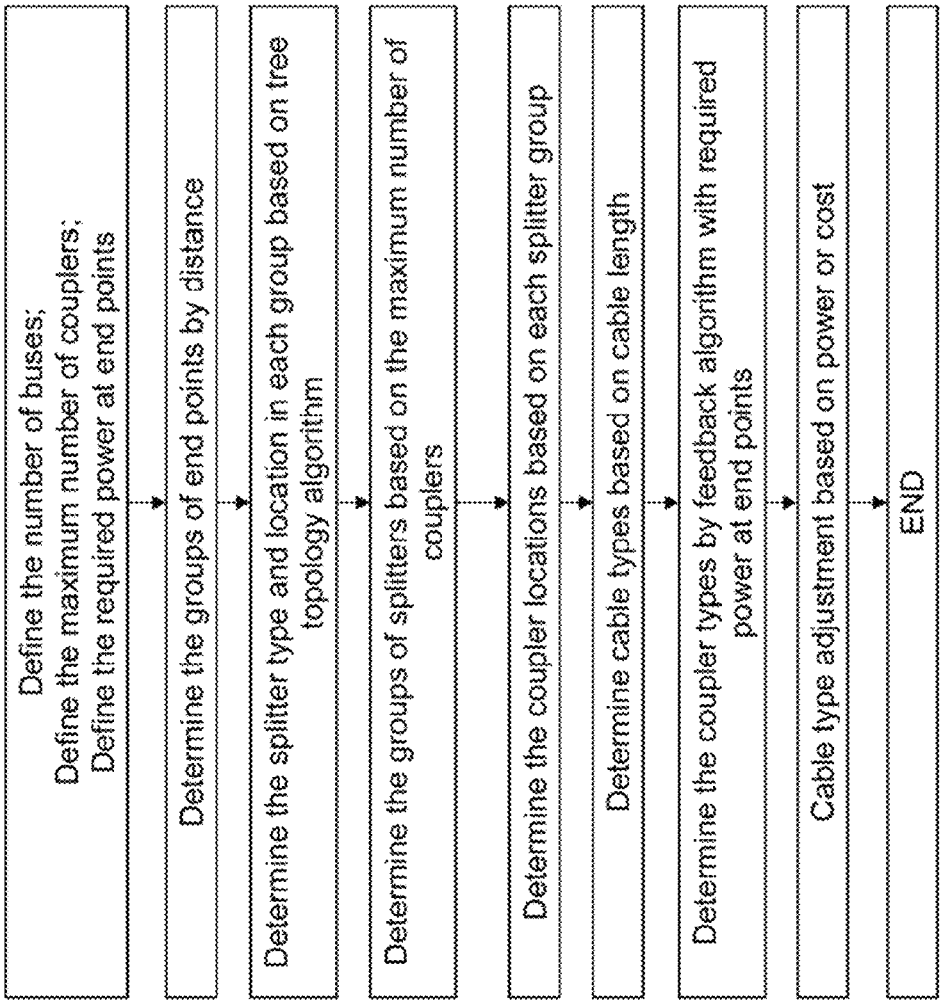

Define the number of buses;
Define the maximum number of couplers;
Define the required power at end points
Determine the groups of end points by distance
Determine the splitter type and location in each group based on tree topology algorithm
Determine the groups of splitters based on the maximum number of couplers
Determine the coupler locations based on each splitter group
Determine cable types based on cable length
Determine the coupler types by feedback algorithm with required power at end points
Cable type adjustment based on power or cost
END

FIG. 21

AUTOMATIC DETERMINATION OF COMPONENT TYPES AND LOCATIONS FOR WIRELESS NETWORK DESIGN

CROSS REFERENCE TO RELATED APPLICATIONS

This application is a continuation of and claims benefit to International Application No. PCT/SG2013/000003 filed on Jan. 3, 2013, entitled "Automatic Determination of Component Types and Locations for Wireless Network Design", which is incorporated by reference for all purposes.

FIELD OF THE INVENTION

The present invention relates to wireless network design. In particular, although not exclusively, the invention relates to automatic determination of component types and/or locations.

SUMMARY OF THE INVENTION

According to a first aspect, a computer implemented method of determining component types and locations in a network design is provided, the method including:

determining, by a computer processor, the component types and locations according to a riser location as an entry point and antenna locations as a plurality of end points, in a floor plan,

determining, by a computer processor, the minimum required transmission power at a riser location to meet antenna equivalent isotropically radiated power (EIRP) requirements in a floor plan;

determining, by a computer processor, the best riser location from available riser locations according to cost limitation or power transmission efficiency in a floor plan;

determining, by a computer processor, the component types and their locations according to a Base Transceiver Station (BTS) location as an entry point and riser locations in different floors as a plurality of end points, in a building plan;

determining, by a computer processor, the minimum required BTS transmission power to meet said minimum required transmission power at each riser location calculated;

updating, by a computer processor, the component locations based upon areas specified as component non-placement areas;

determining, by a computer processor, the initial types of cables according the lengths of each cable;

adjusting, by a computer processor, the sizes of some cables to increase power transmission efficiency from a BTS to antennas if the total cost budget allows;

adjusting, by a computer processor, the sizes of some cables to reduce the cable cost with the satisfaction of the antenna EIRP requirement;

determining, by a computer processor, types and locations of new components, and updating, by a computer processor, existing component types, according to the locations of new antennas for the system upgrade or enhancement.

Preferably, the computer implemented method of determining component types and locations according to an entry point and a plurality of end points in a floor plan or in a building plan include,

determining the number, types and locations of splitters and cable types according to an entry point and a plurality of end points, in a tree topology;

determining the number, types and locations of couplers and cable types according to an entry point and a plurality of end points, in a bus topology;

determining the number, types and locations of splitters, couplers and cable types according to an entry point and a plurality of end points, in a hybrid topology;

determining the minimum required transmission power at an entry point according to the minimum required power at each end point in a tree, bus or hybrid topology.

Preferably, the option to choose tree, bus or hybrid topology in a floor plan or a building plan is determined based upon the floor plan, building plan, product availability, or by any other suitable means.

Preferably, the steps of determining the number, types and locations of splitters in a tree topology includes,

determining the number, types and locations of a first set of splitters, wherein each end point is connected to one splitter of the first set of splitters; and

subsequently determining the number, types and locations of one or more further splitters, wherein each of the first set of splitters is connected by the one or more further splitters.

Preferably, the steps of determining number, types and locations of splitters to be connected to a plurality of end points in a tree topology include,

defining types of available splitters by deciding the maximum outputs of splitters;

determining number and types of splitters from available types of splitters based at least partly on the number of a plurality of end points and the remainder relationship between the number of splitter outputs and end points;

determining a group including one or two splitters, the number of outputs of which is smaller than the predefined number of maximum outputs;

determining the locations of splitters in said group based at least partly on locations of the plurality of end points to be connected and the cable length;

determining the locations of the remaining splitters based at least partly on the length of cables and the locations of the plurality of end points to be connected.

Preferably, the maximum outputs of splitters may be determined based on product availability, or by any other suitable means.

Preferably, the minimum required transmission power at a riser location, is calculated based upon the required transmission power at antennas, the power loss of cables and the insertion loss of splitters.

Preferably, the steps of determining types of splitters to be connected to splitters connected to a plurality of end points in a tree topology include, determining the number, types and locations of one or more further sets of splitters according to the number of pre-existing splitters as the end points based on computer executable instructions for performing the previously mentioned methods for determining:

(i) the number, types and locations of splitters in a tree topology,

(ii) the number, types and locations of splitters to be connected to a plurality of end points in a tree topology, and

(iii) the maximum outputs of splitters based on product availability, or by any other suitable means;

determining the type and location of the last splitter to be connected to an entry point, then all end points are connected to the said last splitter via one or more further set of splitters.

Preferably, the steps of determining the number, types and locations of couplers in a bus topology include,

defining the number and orientation of buses, which are cable backbones;

grouping the end points according to said number and orientation of buses based upon the distance from each end point to the bus;

determining the locations of buses according to the locations of the end points in said respective groups;

determining the locations of couplers along the cable backbones according to said end points to be connected by couplers;

determining the types of couplers to be connected to said end points from available types of couplers based on the required transmission power at the end points.

Preferably, the options of the number and orientation of buses in a floor plan or a building plan are determined based upon the floor plan, building plan, product availability, or by any other suitable means.

Preferably, the steps of determining the types of said couplers includes,

determining the types of couplers by the order from the coupler closest to the entry point to the coupler closest to the end points;

searching the type of each coupler from available coupler types to just meet the minimum power requirement at each end point according to the power level at the entry point;

updating the types of couplers to balance the power allocated at each end point by increasing the minimum power requirement at each end point.

Preferably, the power level at the entry point is initialized in the start stage and then updated according to the available coupler types and the minimum power requirements at the end points.

Preferably, the power at each end point is calculated based upon the coupling loss and direct loss of each coupler.

Preferably, the steps of determining the number, types and locations of splitters and couplers in a hybrid topology include,

defining the maximum cable length, which is a threshold, from the end points to the bus(es) to determine the end points to be connected by couplers, and the end points to be connected by splitters;

connecting the end points that have a cable length less than a threshold directly to the bus(es) via couplers;

determining the types and locations of couplers based on computer executable instructions for performing the previously mentioned methods wherein

(i) the number, types and locations of couplers in a bus topology are determined,

(ii) options of the number and orientation of buses in a floor plan or a building plan are determined based upon the floor plan, building plan, product availability, or by any other suitable means,

(iii) the types of said couplers are determined,

(iv) the power level at the entry point is initialized in the start stage and then updated according to the available coupler types and minimum power requirements at end points, and

(v) the power at each end point is calculated based upon the coupling loss and direct loss of each coupler;

connecting the remaining end points to the bus(es) via splitters;

determining the types and locations of splitters based on computer executable instructions for performing the previously mentioned methods for determining

(i) the number, types and locations of splitters in a tree topology,

(ii) the number, types and locations of splitters to be connected to a plurality of end points in a tree topology,

(iii) the maximum outputs of splitters based on product availability, or by any other suitable means,

(iv) the minimum required transmission power at a riser location, calculated based upon the required transmission power at antennas, the power loss of cables and the insertion loss of splitters, and

(v) the types of splitters to be connected to splitters connected to a plurality of end points in a tree topology;

connecting the splitters to the bus(es) via couplers.

Preferably, the said maximum cable length is defined based upon the floor plan, building plan, product availability, or by any other suitable means.

Preferably, the end points to be connected by splitters and couplers can also be determined according to the cable lengths from the entry point to the end points.

Preferably, the minimum requirement transmission power at the entry point is calculated based on the required power at the end points.

Preferably, the best riser location could be different in the tree, bus and hybrid networks as there may be no single best location for all three topologies.

Preferably, some cables are selected to be adjusted in size by searching all cables in the network and verifying the total cost budget or required transmission power at the entry point and end points.

Preferably, adding new components and updating existing components for system upgrade and enhancement so as to avoid many changes to the current network structure.

Preferably, required transmission power at the entry point is re-calculated in cases of network design for system upgrade and enhancement.

Preferably, a set of solutions to connect an entry point to a plurality of end points is derived, the best solution from them can be chosen according to the specific requirements from design specification, building environments determined by floor plans and building plans, limitation of transmission power, cost budget, etc.

Preferably, the method further includes:

determining that an endpoint of the plurality of endpoints has a transmission power difference with the required transmission of the endpoint greater than a threshold;

increasing the required transmission power for each of the endpoints of the plurality of endpoints by a predetermined increment;

determining the component types and locations based upon at least the increased transmission power requirements.

BRIEF DESCRIPTION OF THE DRAWINGS

To assist in understanding the invention and to enable a person skilled in the art to put the invention into practical effect, preferred embodiments of the invention are described below by way of example only with reference to the accompanying drawings, in which:

FIGS. **1***a*-**1***d* diagrammatically illustrates antenna connections with different types of splitters, according to the prior art;

FIGS. **2***a*-**2***c* diagrammatically illustrates tree, bus and hybrid topologies, according to the prior art;

FIG. **3** diagrammatically illustrates a method for determining splitter types and locations, according to an embodiment of the present invention;

FIG. **4** illustrates a method of determined a minimum required transmission power at an entry point, according to an embodiment of the present invention;

FIGS. **5***a*-**5***b* illustrates results of the method of FIG. **4** on a floor of a building;

FIG. **6** illustrates a method **600** of determining the types and locations of components, according to an embodiment of the present invention;

FIGS. **7***a*-**7***b* illustrates results of the method of FIG. **6** on a floor of a building;

FIG. **8**(*a*) and FIG. **8**(*b*) illustrate results of the method of FIG. **6** with the hybrid topology;

FIG. **9**(*a*) illustrates results of the method of FIG. **6** with 2 buses with different bus directions, FIG. **9**(*b*) illustrates results of the method of FIG. **6** with 2 buses with the same bus direction, FIG. **9**(*c*) illustrates results of the method of FIG. **6** with 3 buses with different bus directions, and FIG. **9**(*d*) illustrates results of the method of FIG. **6** with 3 buses with the same bus directions;

FIG. **10** illustrates an example of a building with multiple floors and the required transmission power on each floor;

FIG. **11**(*a*) illustrates results of splitter types and locations, and actual transmission power at each riser location for a vertical tree topology with maximum splitter output **4**, and FIG. **11**(*b*) illustrates results of splitter types and locations, and actual transmission power at each riser location for a vertical tree topology with maximum splitter output **5**;

FIG. **12**(*a*) and FIG. **12**(*b*) illustrate results of a vertical bus topology and a vertical hybrid topology respectively;

FIG. **13**(*a*) and FIG. **13**(*b*) illustrate the tree topology and the basic hybrid topology combined;

FIG. **14**(*a*) illustrates the basic hybrid topology with two buses, and FIG. **14**(*b*) illustrates the basic hybrid topology with three buses;

FIG. **15** diagrammatically illustrates a method **1500** of adjusting the cable size, according to an embodiment of the present invention;

FIG. **16** describes a method of reducing the cost further;

FIG. **17***a* illustrates a convex shape and FIG. **17***b* illustrates a concave shape of a non-placement area;

FIG. **18** illustrates a floor plan, including possible riser location options;

FIG. **19** illustrates a system upgrade and adjustment solution according to an embodiment of the present invention;

FIG. **20** diagrammatically illustrates a computer, according to an embodiment of the present invention.

FIG. **21** illustrates a selection of component types in a hybrid topology.

Those skilled in the art will appreciate that minor deviations from the layout of components as illustrated in the drawings will not detract from the proper functioning of the disclosed embodiments of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Embodiments of the present invention comprise systems and methods determining component types and locations in a network design. Elements of the invention are illustrated in concise outline form in the drawings, showing only those specific details that are necessary to the understanding of the embodiments of the present invention, but so as not to clutter the disclosure with excessive detail that will be obvious to those of ordinary skill in the art in light of the present description.

In this patent specification, adjectives such as first and second, left and right, front and back, top and bottom, etc., are used solely to define one element or method step from another element or method step without necessarily requiring a specific relative position or sequence that is described by the adjectives. Words such as "comprises" or "includes" are not used to define an exclusive set of elements or method steps. Rather, such words merely define a minimum set of elements or method steps included in a particular embodiment of the present invention.

According to one aspect, the invention resides in a method of determining component types and locations in a network design is provided. The method includes automatically determining component types and locations according to a riser location as an entry point and antenna locations as a plurality of end points, wherein the component types include at least splitters, couplers and cables and the automatically determining component types and locations includes: determining, by a processor of the computer, a first set of component types and locations according to a tree topology, according to the entry point and the plurality of end points; determining, by the processor, a second set of component types and locations according to a hybrid topology, according to the entry point and the plurality of end points; and determining, by the processor, one of the first set of component types and locations and the second set of component types and locations; wherein the steps of determining the component types and locations are based upon at least one of antenna equivalent isotropically radiated power (EIRP) requirements, a Base Transceiver Station (BTS) maximum transmission power, a maximum cable length, and a cost limitation.

Advantages of some embodiments of the present invention include guaranteeing the requirements of installed antennas, transmission power or financial budget. Additionally, network upgrade is simplified. These capabilities provide a user with a powerful and flexible design environment for wireless networks, which allows users to quickly and easily achieve optimal solutions with lowest cost for designing multiple service coverage areas according to different defined requirements.

Before describing embodiments of the present disclosure in detail, it is helpful to describe connections in a communications environment in which the invention may be implemented and components of the embodiments individually.

FIG. **1** diagrammatically illustrates antenna connections with different types of splitters, according to the prior art. FIG. **1**(*a*) illustrates a splitter **105** and three antennas **110**, wherein each antenna **110** is connected by cable **115** to a coupling port of the splitter **105**. FIG. **1**(*b*) illustrates a splitter **105** and two antennas **110**, FIG. **1**(*c*) illustrates a splitter **105** and five antennas **110**, and FIG. **1**(*d*) illustrates a splitter **105** with four antennas **110**. As will be readily understood by a person skilled in the relevant art(s), the present invention is not restricted by a number of antennas **110** that may be connected to the splitter **105**.

FIG. **2** diagrammatically illustrates tree, bus and hybrid topologies, according to the prior art.

FIG. **2**(*a*) diagrammatically illustrates a tree topology, wherein a plurality of antennas **110** is connected directly by cables to splitters **105**.

FIG. **2**(*b*) diagrammatically illustrates a bus topology, wherein a plurality of antennas **110** are connected by cables to couplers **205**. Each antenna is connected by cable to a coupling port of the couplers **205** and the connection of all direct ports forms the backbone.

FIG. **2**(*c*) diagrammatically illustrates a hybrid topology. Antennas **110** are connected by cables to the coupling ports of couplers **205** directly or through the splitters **105**.

Generally, the tree topology, as illustrated for example in FIG. **2**(*a*), balances the antenna equivalent isotropically radiated powers (EIRPs) better than the bus and hybrid topologies, as illustrated for example in FIGS. **2**(*b*) and **2**(*c*) respectively, because of the equal power division by splitters **105** in the tree topology. However, the tree topology requires more

parallel cables. In the bus topology, as illustrated in FIG. **2**(*b*) for example, only couplers are used and cable can be saved relative to the tree topology, but the antenna EIRPs are unbalanced. For these reasons, tree and hybrid topologies are the popular solutions for the indoor network design.

The cable size selection between components is initially based on the cable length. ½", ⅞", 1¼" and 1⅝" cables are the four most common cable sizes. The larger sized cable has less power attenuation but a higher cost, while the cable with the smaller size has high power loss and low cost. Therefore, the cable types are selected by the example criteria in the following table before the determination of other components' types and locations.

TABLE 1

An example of cable selection based on the cable length

Size	Cable length
½"	0 < Cable length ≤ 20 m
⅞"	20 < Cable length ≤ 50 m
1¼"	50 < Cable length ≤ 150 m
1⅝"	Cable length > 150 m

To calculate the total cost, a unit price of each type of components is used. The following table lists example prices.

TABLE 2

An example of unit prices of splitters, couplers and cables

Splitter/Coupler	Unit Price
2-way splitter	$38
3-way splitter	$48
4-way splitter	$58
5-way splitter	$68
3 dB coupler	$38
6 dB coupler	$38
10 dB coupler	$40
15 dB coupler	$40
20 dB coupler	$40

Cable Type	Cable Price	Connector
½"	$3.50/m	$10.50
⅞"	$6.50/m	$15.00
1¼"	$13.80/m	$56.00
1⅝"	$50.00/m	$80.00

Tree Topology

To determining component types and locations according to a tree topology, types and locations of splitters are determined according to an entry point and a plurality of end points.

A riser location can be used as an entry point and antenna locations as the plurality of end points, or a Base Transceiver Station (BTS) can be used as the entry point and riser locations can be used as end points, for example. This enables the determination of component types to be applicable to levels of a building, or between levels of a building, for example.

FIG. **3** diagrammatically illustrates a method **300** for determining splitter types and locations, according to an embodiment of the present invention.

In step **305**, the method is initiated with a number of components, N_T, and a location for each of the components. The components are initially the end points, for example antennas or risers.

In step **310**, the maximum number of splitter outputs, $w_{s,max}$, is determined. The maximum number of splitter outputs may be determined based on product availability, or by any other suitable means.

In step **315**, a number of splitters and splitter types are determined. The number of splitters is the number of splitters required to connect directly to the components, may not be the total number of splitters.

When $N_T<2w_{s,max}$, two splitters are sufficient to connect the components. The smallest two suitable splitter types are chosen.

When $N_T\geq 2w_{s,max}$, the splitter types and numbers are determined by:

i. If $\mathrm{mod}(N_T,w_{s,max})\neq 1$, the number of splitters with $w_{s,max}$ outputs, N_0, is determined as $N_0=\mathrm{floor}(N_T/w_{s,max})$. The numbers of splitters with $w_{s,1}$ outputs is 1, where $w_1=\mathrm{mod}(N_T,w_{s,max})$.

ii. If $\mathrm{mod}(N_T,w_{s,max})=1$, $w_{s,max}$ is updated to $w_{s,max}=w_{s,max}-1$.

a. If $\mathrm{mod}(N_T,w_{s,max})\neq 1$, with the updated $w_{s,max}$, $N_0=\mathrm{floor}(N_T/w_{s,max})$ and $w_3=\mathrm{mod}(N_T,w_{s,max})$.

b. If $\mathrm{mod}(N_T,w_{s,max})=1$, with the updated $w_{s,max}$, $N_0=\mathrm{floor}(N_T/(w_{s,max}+1))$ and $w_{s,1}=N_T-N_0\cdot w_{s,max}$.

As will be readily understood by a person skilled in the art, the mod(x, y) function finds the remainder of division of one number by another, e.g. mod(17,4)=1.

For example, when $w_{s,max}$ is 4 and the numbers of components, N_T, is 13, the numbers of required 3-way splitters are $N_0=3$, and one 4-way splitter is required as well because $w_{s,1}=4$.

In step **320**, the splitter locations are determined. At any given time, let CL(a) denote the least cable length between a component $a\in A$ and the closest splitter s. a and s are two-dimensional vectors denoting a component and splitter location respectively, and $\{a_x,a_y\}$ and $\{s_x,s_y\}$ represent their Cartesian coordinates.

If $w_{s,1}\neq 0$, a component near the edge of the group of components is chosen along with its closest $w_{s,1}-1$ neighbouring components. In a floor plan, this component can correspond with a corner of the building, or if applying the method vertically, the top or bottom of the building. These components are connected by a $w_{s,1}$-way splitter, with the location of

$$(s_{0,x},s_{0,y})=\left(\frac{\sum_{i=1}^{w_{s,1}}a_{i,x}}{w_{s,1}},\frac{\sum_{i=1}^{w_{s,1}}a_{i,y}}{w_{s,1}}\right).$$

The remaining unconnected N_T-w_s components are connected by N_0 splitters, each with $w_{s,max}$. outputs. In the $N_T-w_{s,1}$ components, a component, a_1, is chosen at random as a splitter location to be included in the defined splitter selection, Λ.

Assuming

$$\Gamma_j=\frac{CL(a_j)^2}{\sum_{i=1}^{N_T-w_{s,1}}CL(a_i)^2},$$

the next splitter location, $a_j\in\{1,2,\ldots,N_T-w_{s,1}\}$ and $a_j\notin A$, is determined which results in $\Gamma_j=\max\{\Gamma_2,\Gamma_3,\ldots,\Gamma_j,\ldots,\Gamma_K\}$. Then a_j is contained into Λ. This is repeated until all the N_0 splitter locations have been chosen and included in Λ.

Starting with a splitter location, k, the $w_{s,max}$ components with the shortest cable length to the splitter are determined, and the splitter location is updated according to

$$(s_{k,x}, s_{k,y}) = \left(\frac{\sum_{i=1}^{w_{s,max}} a_{i,x}}{w_{s,max}}, \frac{\sum_{i=1}^{w_{s,max}} a_{i,y}}{w_{s,max}} \right).$$

The process is repeated for each splitter, however only considering components not allocated to an earlier splitter, until all N_0 splitter locations have been updated.

At step **330**, it is determined if the number of splitters placed is bigger than the maximum number of splitter outputs, $N_S > w_{s,max}$. If no, one splitter is sufficient to connect the splitters and this is performed in step **330**. If yes, more than one splitter is needed and steps **310** to **325** are repeated using the splitters and splitter locations as the components, N_T. The process is repeated until all splitters are connected.

FIG. **4** illustrates a method **400** of determined a minimum required transmission power at an entry point, according to an embodiment of the present invention. The minimum required transmission power at the entry point is calculated based upon end point power loss and end point EIRP requirements after the splitter types and locations are determined.

At step **405**, the required power at the entry point is initialised to an initial value, for example 0. In order to guarantee the power requirements, a backward feedback is adopted to adjust the power at an entry point.

At step **410**, the splitter types and locations are determined. The splitter types and locations can be determined using the method **300** of FIG. **3**.

At step **415**, the power loss for each end point is determined. The power loss from each end point to an entry point can be calculated as a summation of the splitter insertion loss and cable loss. The power loss of cables depends on the signal frequency, length and quality. Theoretical splitter insertion loss values with different output numbers can be used, or alternatively empirical insertion loss values can be used. Example splitter insertion loss values are shown in the table below.

TABLE 3

Example splitter insertion loss values (dB) with numbers of splitter outputs

Numbers of splitter outputs	Splitter Insertion loss (dB)
2	3.01
3	4.77
4	6.02
5	6.99
6	7.78
7	8.45
8	9.03
9	9.54
10	10.00
11	10.41
12	10.79

At step **420**, the EIRP is calculated for each end point. The end point EIRP is calculated by subtracting the power loss from the power at the entry point.

At step **425**, the EIRP for each end point is compared with the target end point EIRP. If the target EIRP is not met, the power at the riser is updated by adding a delta, Δ, at step **430**, and steps **415** to **425** are repeated until all end point EIRP values are satisfied. According to an embodiment, Δ is set to 0.1 dBm. The power at the entry point which results in the target end point EIRPs being met, i.e. at step **435**, is the required minimum transmission at the entry point.

The method **400** of FIG. **4** may be applied to a floor of a building, or across floors of a building, for example.

FIG. **5** illustrates results of the method **400** of FIG. **4** on a floor of a building. FIG. **5**(*a*) illustrates the results of the method **400** when $w_{s,max}=4$. In total 13 splitters are used and a 4-way splitter is placed at the riser location to connect other splitters. FIG. **5**(*b*) illustrates the results of the method **400** when $w_{s,max}=5$. 10 splitters are used.

TABLE 4

The antenna EIRPs and costs of the results of FIG. 5(a)

Antenna No.	Antenna EIRP(dBm)
#1	5.1123
#2	5.1123
#3	1.669
#4	1.3228
#5	1.5741
#6	1.2696
#7	1.2086
#8	2.1873
#9	1.4214
#10	1.1545
#11	1.384
#12	1.7707
#13	2.054
#14	1.3258
#15	1.6408
#16	1.9268
#17	1.8501
#18	1.7141
#19	1.9859
#20	1.2941
#21	1.3639
#22	1.6845
#23	1.1447
#24	1.9628
#25	1.4867
#26	1.1371
#27	0.83251
#28	1.8651
#29	1.5722
#30	0.85465

Required/Current Riser Power (dBm)	21
Total EIRP (dBm)	16.66
Total cost ($)	3063.6

Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	654	0	1500.6	909

Splitter types	4-way	5-way
Number of splitters	13	0

Cable types	½"	⅞"	1¼"	1⅝"
Cable length (m)	300	70	0	0
Number of connectors	78	6	0	0

TABLE 5

The antenna EIRPs and costs of the results of FIG. 5(b)

Antenna No.	EIRP (dBm)
#1	1.1373
#2	1.1759
#3	1.7985

TABLE 5-continued

The antenna EIRPs and costs of the results of FIG. 5(b)	
#4	1.0174
#5	1.0563
#6	1.2875
#7	1.6951
#8	1.3939
#9	1.3329
#10	1.2287
#11	1.0174
#12	0.74961
#13	1.439
#14	0.79069
#15	0.98824
#16	1.1264
#17	1.5757
#18	1.0231
#19	0.83308
#20	1.0505
#21	0.90456
#22	1.374
#23	0.61896
#24	0.93795
#25	0.50852
#26	0.33146
#27	1.1555
#28	1.3322
#29	0.69057
#30	0.73169

Required/Current Riser Power (dBm)	20
Total EIRP (dBm)	15.89
Total cost ($)	2739.4

Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	570	0	1341.4	828

Splitter types	4-way	5-way
Number of splitters	0	10

Cable types	½"	⅞"	1-¼"	1⅝"
Cable length (m)	341.9	22.27	0	0
Number of connectors	76	2	0	0

The above tables illustrate the antenna EIRPs and costs of the results of FIGS. **5**(*a*) and **5**(*b*) respectively, with the EIRP requirement of 0 dBm. As can be seen from the tables, most antenna EIRPs are well balanced and the total component cost of $w_{s,max}$=5 is less than that of $w_{s,max}$=4 due to fewer splitters and less cable.

Bus and Hybrid Topology

To set up a bus or hybrid topology, a maximum cable length from the end points to the bus (cable backbone), L_{max}, is chosen. A pure bus topology corresponds with L_{max} being infinity. This means all end points will be connected to the cable backbone by couplers with bus topology. If L_{max} is 1 m, for example, only the end points the cable length from which to the backbone are less than 1 m will be connected with bus topology. The remaining end points are processed according to the tree topology described earlier, and the splitters are connected to the couplers on the cable backbone.

Different numbers of buses or cable backbones give different solutions and a solution is provided according to the maximum BTS transmission power or component cost limitation from the solutions with different bus numbers from zero (tree topology) to a predefined one, e.g., 4.

FIG. **6** illustrates a method **600** of determining the types and locations of components, according to an embodiment of the present invention. The type of coupler is decided by its coupling loss.

The total numbers of available couplers is denoted N_c with T types of the coupling losses (dB) of $\{C_j\}_{j=1}^{T}$ at the coupling ports, where $C_1>C_2>\ldots C_T$. The insertion losses (dB) at the direct ports of the couplers are $\{D_j\}_{j=1}^{T}$. The coupler group from 1 to N_c are ranked with ascending cable length from the riser location to the couplers and the ith coupler (i=1) is the closest coupler to the riser or power transmitter in the floor.

In step **605**, the method is initialised. The required power at the entry point is set to 0, the number of buses is defined and variables are initialised, i=1, j=1. This means the coupler closest to the entry point is initialized with the coupling loss of C_1.

In step **610**, the bus location and coupler locations are determined. Initially, the centre C_a of all end points, $\{c_{a,x}, c_{a,y}\}$, is determined by

$$c_{a,x}=\frac{\sum_{i=1}^{N_T} a_{i,x}}{N_T}$$

and

$$c_{a,y}=\frac{\sum_{i=1}^{N_T} a_{i,y}}{N_T}.$$

The bus passes through C_a if the bus number is 1. If the bus numbers are b, (b>1), the end points are separated into b groups. The centre of each group is calculated with the same calculation as that when the bus number is 1. The b buses will path through these centres respectively.

At step **615**, it is determined for each end point if the distance to a bus is shorter than L_{max}. If yes, the end points are connected to the bus directly in step **620**, and a coupler is placed at the intersection of each cable and the bus. If no, the end points with a distance to the bus(es) longer than L_{max}, are connected by splitters in step **625**, as determined by the tree topology discussed earlier, with a coupler are placed at the intersections of the bus(es) being the entry point.

In step **630**, the EIRP is calculated for the end points, the power of which is transmitted through the coupler i with the coupling loss of C_j. The end point

$$EIRP=\text{power\_at\_entrypoint}-\left(C_j+\sum_{m=1}^{j-1} D_m\right)$$

and

$$EIRP=\text{power\_at\_entrypoint}-\left(C_j+SP_j+\sum_{m=1}^{j-1} D_m\right)$$

if the end point is connected to the coupler directly and through the splitter i with the splitter loss of SP_j.

If the end point EIRP requirement is not satisfied, it is determined in step **635** if all coupler types have been tried. If no, the type of the coupler j is updated by j=j+1 in step **640**. This means that the coupler with less coupling loss is used and, the antenna EIRP is recalculated in step **630**. This process is repeated until the antenna EIRP requirement is met or all coupler types have been tried. When all coupler types have

been tried, i.e. j>T, it is determined if the antenna EIRP requirement has been updated in step **645**, the power at the entry point is increased by Δ_a in step **650**. Δ_a can be 0.5 dB or 1 dB, for example. The process from step **630** is then repeated with the updated power at the entry point.

If the antenna EIRP requirement is satisfied, in step **655** it is determined if all types of couplers have been tested. If not, the next coupler is decided in step **660** and the EIRP is determined according to step **630** until all types of couplers are determined.

Once all antenna EIRPs are guaranteed based on the coupler type determination, it is possible that the antennas, $\{a_m\}_{m=1}^{X}$, connected to the last coupler are allocated the remaining transmission power, which results in that the EIRP of those antennas are higher than the EIRP requirement for a certain value, Δ_b, e.g., 1 dB or 3 dB. The antenna EIRPs are thus unbalanced and this is determined in step **665**.

If yes, the remaining transmission power is allocated by step **670**, where the antenna EIRP requirement $EIRP_{req}$ is increased according to $EIRP_{req}=EIRP_{req}+\Delta_c$ to re-determinate the coupler types according to the steps above. Δ_c can be set as 0.1 or 0.05 dB, for example. The smaller A. helps to get more balanced antenna EIRPs. The final coupler types will be determined when the gap between the EIRPs of $\{a_m\}_{m=1}^{X}$ and updated $EIRP_{req}$ is smaller than Δ_b.

The coupler types are saved in step **670**, such that if the EIRP requirements are not met, and all coupler types have been tried, the latest update of EIRP requirement will be cancelled and the determination of the coupler types will revert to the previous solution in step **675**.

FIG. **7** illustrates results of the method **600** of FIG. **6** on a floor of a building. FIG. **7**(*a*) illustrates an example where a single bus is used, and FIG. **7**(*b*) illustrates an example where two buses were used.

TABLE 6

Details of the results of FIG. 7(a)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	20	(10.3851,60)	6.0578
#2	20	(20.397,60)	4.8814
#3	20	(23.2715,59)	3.4587
#4	20	(23.2715,54.9316)	3.4493
#5	20	(23.2715,53.0165)	2.2398
#6	20	(23.2715,47.7041)	2.1057
#7	20	(23.2715,46.4632)	0.752
#8	20	(23.2715,44.9696)	0.5255
#9	20	(23.2715,44.2522)	0.8992
#10	15	(23.2715,39)	4.6543
#11	15	(23.2715,39)	3.5302
#12	15	(23.2715,37.5236)	3.5015
#13	15	(23.2715,36.5978)	4.1018
#14	15	(23.2715,32.2522)	2.7688
#15	15	(23.2715,31)	1.7879
#16	15	(23.2715,30.9614)	1.4247
#17	15	(23.2715,28.0148)	1.8372
#18	15	(23.2715,25.5502)	0.5978
#19	15	(23.2715,25.3301)	0.8253
#20	10	(23.2715,20.9597)	5.0158
#21	10	(23.2715,20.9303)	3.2944
#22	10	(23.2715,20.865)	2.8551
#23	10	(23.2715,16.4387)	1.9812
#24	10	(23.2715,16.2781)	1.9639
#25	10	(23.2715,15)	0.7036
#26	6	(23.2715,10.9093)	2.7757
#27	6	(23.2715,8.9696)	1.4571
#28	6	(23.2715,8.9188)	0.1868
#29	3	(23.2715,8.865)	2.1998
#30	0	(23.2715,8.865)	1.6475

TABLE 6-continued

Details of the results of FIG. 7(a)

Antenna No.	Coupler type (dB)	Coupler Location			EIRP (dBm)
Required/Current Riser Power (dBm)			27		
Total EIRP (dBm)			17.48		
Total cost ($)			4038.3		
Component types		Splitter	Coupler	Cable	Connector
Component cost ($)		0	1156	992.27	1890
Splitter types		4-way	5-way		
Number of splitters		0	0		
Number of couplers		29			
Cable types		1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)		283.5	0	0	0
Number of connectors		180	0	0	0

TABLE 7

Details of the results of FIG. 7(b)

Antenna No.	Coupler type (dB)	Coupler Location			EIRP (dBm)
#1	15	(10.3851,60)			4.0578
#2	15	(20.397,60)			2.8814
#3	15	(23.2628,59)			1.4587
#4	10	(23.2628,54.9316)			1.4493
#5	10	(23.2628,53.0165)			5.2398
#6	10	(23.2628,47.7041)			4.7074
#7	10	(23.2628,46.4632)			2.9538
#8	10	(23.2628,44.9696)			2.3255
#9	10	(23.2628,44.2522)			2.2992
#10	6	(23.2628,39)			4.6561
#11	6	(23.2628,39)			2.232
#12	6	(23.2628,37.5236)			0.9015
#13	3	(23.2628,36.5978)			3.2018
#14	0				1.9688
#15	15	(5,30.9614)			5.7054
#16	15	(8.9188,18.616)			4.1197
#17	15	(8.9433,18.616)			3.2677
#18	15	(16.9022,18.616)			2.5736
#19	15	(16.9303,18.616)			1.651
#20	15	(18.9131,18.616)			1.8983
#21	10	(20.9001,18.616)			5.6769
#22	10	(23,18.616)			4.727
#23	10	(25.42,18.616)			4.5358
#24	10	(27,18.616)			3.2289
#25	10	(27,18.616)			2.2194
#26	10	(32.2807,18.616)			1.7531
#27	6	(32.397,18.616)			4.5565
#28	6	(32.8993,18.616)			2.629
#29	3	(35,18.616)			4.5687
#30	0				3.3359
Required/Current Riser Power (dBm)			24.76		
Total EIRP (dBm)			18.21		
Total cost ($)			4155.6		
Component types		Splitter	Coupler	Cable	Connector
Component cost ($)		0	1074	1182.6	1899
Splitter types		4-way	5-way		
Number of splitters		0	0		
Number of couplers		28			
Cable types		1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)		145.33	71.38	0	0
Number of connectors		94	32	0	0

Tables 6 and 7 provide details of the coupler types and locations, actual antenna EIRPs, required transmission at the riser, cost and other component particulars of the results of FIG. **7**(*a*) and FIG. **7**(*b*) respectively. Due to the unbalanced power at the coupler outputs, the actual antenna EIRPs are also not balanced, but meet the EIRP requirement of 0 dBm.

More cables are used in the bus topology, so the total component cost is much higher than the tree topology.

FIG. **8**(*a*) and FIG. **8**(*b*) illustrate results of the method **600** of FIG. **6** with the hybrid topology determined by L_{11}=1 m and $w_{s,max}$=4 and $w_{s,max}$=5 respectively.

TABLE 8

Details of the types and locations of splitters and couplers of FIG. 8(a)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	15	(23.2715,53.7976)	1.6796
#2			1.6796
#3			1.6796
#4	10	(23.2715,52.9794)	4.6974
#5			4.6974
#6			4.6974
#7			4.6974
#8	10	(23.2715,41.4877)	4.2017
#9			4.2017
#10			4.2017
#11	15	(23.2715,36.5978)	5.0738
#12	10	(23.2715,36.257)	0.95144
#13			0.95144
#14			0.95144
#15			0.95144
#16	10	(23.2715,26.6453)	1.117
#17			1.117
#18			1.117
#19	6	(23.2715,22.046)	2.5764
#20			2.5764
#21			2.5764
#22			2.5764
#23	3	(23.2715,13.9396)	2.6416
#24			2.6416
#25			2.6416
#26			2.6416
#27	3	(23.2715,11.3709)	1.4204
#28			1.4204
#29			1.4204
#30	0		7.5718
Required/Current Riser Power (dBm)		25	
Total EIRP (dBm)		17.83	
Total cost ($)		2148.7	
Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	424	278	807.72	639
Splitter types	3-way	4-way		
Number of splitters	4	4		
Number of couplers	9			
Cable types	1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)	185.33	69.41	0	0
Number of connectors	58	20	0	0

TABLE 9

Details of the types and locations of splitters and couplers of FIG. 8(a)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	10	(23.2715,51.234)	3.3711
#2			3.3711
#3			3.3711
#4			3.3711
#5			3.3711
#6	10	(23.2715,49.3712)	2.3043
#7			2.3043
#8			2.3043
#9			2.3043
#10			2.3043
#11	15	(23.2715,36.5978)	4.486

TABLE 9-continued

Details of the types and locations of splitters and couplers of FIG. 8(a)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#12	6	(23.2715,30.3312)	3.5922
#13			3.5922
#14			3.5922
#15			3.5922
#16			3.5922
#17	6	(23.2715,27.9732)	0.9672
#18			0.9672
#19			0.9672
#20			0.9672
#21			0.9672
#22	3	(23.2715,14.2833)	1.698
#23			1.698
#24			1.698
#25			1.698
#26			1.698
#27	3	(23.2715,11.6094)	0.4581
#28			0.4581
#29			0.4581
#30	0		6.784
Required/Current Riser Power (dBm)		24	
Total EIRP (dBm)		17.43	
Total cost ($)		1867.3	
Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	388	238	728.3	513
Splitter types	3-way	4-way	5-way	
Number of splitters	1	0	5	
Number of couplers	7			
Cable types	1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)	157.87	68.7	0	0
Number of connectors	46	16	0	0

Tables 8 and 9 provide details of the types and locations of splitters and couplers of FIG. **8**(*a*) and FIG. **8**(*b*) respectively. The antenna EIRP requirement of 0 dBm is guaranteed and there is not much difference in the required transmission power and cost between the two solutions.

FIG. **9**(*a*) illustrates results of the method **600** of FIG. **6** with 2 buses with different bus directions, FIG. **9**(*b*) illustrates results of the method **600** of FIG. **6** with 2 buses with the same bus direction, FIG. **9**(*c*) illustrates results of the method **600** of FIG. **6** with 3 buses with different bus directions, and FIG. **9**(*d*) illustrates results of the method **600** of FIG. **6** with 3 buses with the same bus directions.

TABLE 10

Details of the results of FIG 9(a)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	10	(15.3911,60)	4.8376
#2			4.8376
#3	6	(23.2628,52.9794)	2.2255
#4			2.2255
#5			2.2255
#6			2.2255
#7	3	(23.2628,43.0418)	2.4172
#8			2.4172
#9			2.4172
#10			2.4172
#11	3	(23.2628,38.0093)	0.4138
#12			0.4138
#13			0.4138
#14	0		7.0018
#15	10	(14.9233,18.616)	1.3982

TABLE 10-continued

Details of the results of FIG 9(a)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#16			1.3982
#17			1.3982
#18			1.3982
#19	6	(16.444,18.616)	4.6028
#20			4.6028
#21			4.6028
#22			4.6028
#23	6	(29.4,18.616)	1.9586
#24			1.9586
#25			1.9586
#26			1.9586
#27		(32.3492,18.616)	2.9117
#28			2.9117
#29			2.9117
#30	0		13.65
Required/Current		24	
Riser Power (dBm)			
Total EIRP (dBm)		19.16	
Total cost ($)		2650.3	
Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	434	236	1259.3	721
Splitter types	2-way	3-way	4-way	
Number of splitters	1	2	5	
Number of couplers	8			
Cable types	1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)	52.7	0	41.67	0
Number of connectors	28	0	10	0

TABLE 11

Details of the results of FIG 9(b)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	10	(30.2575,52.3287)	2.7663
#2			2.7663
#3			2.7663
#4	10	(30.2575,45.2605)	0.7691
#5			0.7691
#6			0.7691
#7	15	(30.2575,32.2522)	0.571
#8	6	(30.2575,28.7347)	0.962
#9			0.962
#10			0.962
#11			0.962
#12	3	(30.2575,16.8244)	2.5629
#13			2.5629
#14			2.5629
#15	0		4.6993
#16			4.6993
#17	10	(15.2876,47.2006)	3.8685
#18			3.8685
#19			3.8685
#20	10	(15.2876,43.0673)	0.7317
#21			0.7317
#22			0.7317
#23			0.7317
#24	6	(15.2876,20.9337)	4.513
#25			4.513
#26			4.513
#27	6	(15.2876,13.4359)	1.2358
#28			1.2358
#29			1.2358
#30			1.2358
Required/Current		24	
Riser Power (dBm)			
Total EIRP (dBm)		18.09	
Total cost ($)		2877.6	

TABLE 11-continued

Details of the results of FIG 9(b)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	538	316	1240.6	783
Splitter types	2-way	3-way	4-way	
Number of splitters	2	5	4	
Number of couplers	9			
Cable types	1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)	133.3	72.5	0	0
Number of connectors	34	12	0	0

TABLE 12

Details of the results of FIG. 9(c)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	6	(14.9233,18.616)	2.3982
#2			2.3982
#3			2.3982
#4			2.3982
#5	6	(16.444,18.616)	0.7028
#6			0.7028
#7			0.7028
#8			0.7028
#9	3	(29.4,18.616)	1.058
#10			1.058
#11			1.058
#12			1.058
#13	0		0.4117
#14			0.4117
#15			0.4117
#16	10	(14.7596,48.0848)	0.8146
#17			0.8146
#18			0.8146
#19	6	(14.7596,47.2006)	1.1067
#20			1.1067
#21			1.1067
#22	6	(29.6403,48.6274)	2.6788
#23			2.6788
#24			2.6788
#25			2.6788
#26	0		2.1299
#27			2.1299
#28			2.1299
#29			2.1299
#30	10	(29.6403,32.2522)	2.0319
Required/Current		23.77	
Riser Power (dBm)			
Total EIRP (dBm)		18.01	
Total cost ($)		3932.8	
Component types	Splitter	Coupler	Cable	Connector
Component cost ($)	608	318	2132.8	874
Splitter types	2-way	3-way	4-way	
Number of splitters	0	4	5	
Number of couplers	7			
Cable types	1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)	77.89	68.73	0	0
Number of connectors	22	8	0	0

TABLE 13

Details of the results of FIG. 9(d)

Antenna No.	Coupler type (dB)	Coupler Location	EIRP (dBm)
#1	10	(15.3911,60)	4.8376
#2			4.8376

TABLE 13-continued

Details of the results of FIG. 9(d)

Antenna No.	Coupler type (dB)	Coupler Location			EIRP (dBm)
#3	6	(23.2628,52.9794)			2.2255
#4					2.2255
#5					2.2255
#6					2.2255
#7	3	(23.2628,43.0418)			2.4172
#8					2.4172
#9					2.4172
#10					2.4172
#11	3	(23.2628,38.0093)			0.41377
#12					0.41377
#13					0.41377
#14	0	(23.2628,36.5978)			7.0018
#15	6	(15.6837,21.3248)			3.619
#16					3.619
#17					3.619
#18	6	(15.6837,20.9337)			1.4135
#19					1.4135
#20					1.4135
#21	0	(15.6837,8.8919)			1.7171
#22					1.7171
#23	6	(30.8746,25.8051)			5.1973
#24					5.1973
#25					5.1973
#26	6	(30.8746,16.8244)			2.263
#27					2.263
#28					2.263
#29	0	(30.8746,12.7042)			3.1252
#30					3.1252
Required/Current Riser Power (dBm)		24.5			
Total EIRP (dBm)		19.8			
Total cost ($)		3733.8			
Component types		Splitter	Coupler	Cable	Connector
Component cost ($)		566	350	1772.8	1045
Splitter types		2-way	3-way	4-way	
Number of splitters		3	6	2	
Number of couplers		8			
Cable types		1/2"	7/8"	1-1/4"	1-5/8"
Cable length (m)		27.15	0	41.66	0
Number of connectors		28	0	10	0

Tables 10 and 11 provide further details of the results of FIG. **9**(*a*) and FIG. **9**(*b*) respectively, and Tables 12 and 13 provide further details of the results of FIG. **9**(*c*) and FIG. **9**(*d*) respectively. The total cost increases with the bus numbers because the cable length increases.

Vertical Topology

Once the types and locations of splitters and couplers are determined horizontally using the methods described earlier, the same methods may be applied to a building vertically. The required transmission power at the riser of each floor is given as the end point requirements.

FIG. **10** illustrates an example of a building with multiple floors and the required transmission power on each floor.

The method **600** of FIG. **6**, the method **300** of FIG. **3** and the method **400** of FIG. **4** are then used vertically using the BTS as the entry point and the risers (one per floor) as end points. The splitters and couplers which connect the components at the riser per floor are then determined.

Since the cable lengths from the riser locations to the bus are the same vertically, an L_{max} need not be defined in the vertical hybrid topology. The main difference between horizontal and vertical topologies is the location calculations of splitters, s_0 and

$$\{s_k\}_{k=1}^{N_0}.$$

Based on the horizontal topology and K building levels, the power at all risers,

$$\{r_k\}_{k=1}^{K},$$

are calculated. Prower(r_k) is defined as the required power at the riser of the kth level. Therefore, the coordinates of s_0 and

$$\{s_k\}_{k=1}^{N_0}$$

can be calculated based on the following formulas,

$$\begin{cases} s_{0,x} = r_{1,x} \cdot \dfrac{\text{Power}(r_{1,k})}{\sum_{i=1}^{w_{s,1}} \text{power}(r_{i,k})} + r_{2,x} \cdot \dfrac{\text{Power}(r_{2,k})}{\sum_{i=1}^{w_{s,1}} \text{power}(r_{i,k})} + \ldots + r_{w_{s,1},x} \cdot \dfrac{\text{power}(r_{w_{s,1},k})}{\sum_{i=1}^{w_{s,1}} \text{power}(r_{i,k})} \\ s_{0,y} = r_{1,y} \cdot \dfrac{\text{Power}(r_{1,k})}{\sum_{i=1}^{w_{s,1}} \text{power}(r_{i,k})} + r_{2,y} \cdot \dfrac{\text{Power}(r_{2,k})}{\sum_{i=1}^{w_{s,1}} \text{power}(r_{i,k})} + \ldots + r_{w_{s,1},y} \cdot \dfrac{\text{power}(r_{w_{s,1},k})}{\sum_{i=1}^{w_{s,1}} \text{power}(r_{i,k})} \end{cases} \text{ and}$$

$$\begin{cases} s_{k,x} = r_{1,x} \cdot \dfrac{\text{Power}(r_{1,k})}{\sum_{i=1}^{w_{s,max}} \text{power}(r_{i,k})} + r_{2,x} \cdot \dfrac{\text{Power}(r_{2,k})}{\sum_{i=1}^{w_{s,max}} \text{power}(r_{i,k})} + \ldots + r_{w_{s,max},x} \cdot \dfrac{\text{power}(r_{w_{s,max},k})}{\sum_{i=1}^{w_{s,max}} \text{power}(r_{i,k})} \\ s_{k,y} = r_{1,y} \cdot \dfrac{\text{Power}(r_{1,k})}{\sum_{i=1}^{w_{s,max}} \text{power}(r_{i,k})} + r_{2,y} \cdot \dfrac{\text{Power}(r_{2,k})}{\sum_{i=1}^{w_{s,max}} \text{power}(r_{i,k})} + \ldots + r_{w_{s,max},y} \cdot \dfrac{\text{power}(r_{w_{s,max},k})}{\sum_{i=1}^{w_{s,max}} \text{power}(r_{i,k})} \end{cases}$$

FIG. **11**(*a*) illustrates results of splitter types and locations, and actual transmission power at each riser location for a vertical tree topology with maximum splitter output **4**, and FIG. **11**(*b*) illustrates results of splitter types and locations, and actual transmission power at each riser location for a vertical tree topology with maximum splitter output **5**.

TABLE 14

Details of the results of FIG. 11(a)					
Required BTS Power (dBm)	38.37				
Total cost ($)	5806.7				
Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	598	0	4185.5	133	133.2
Splitter types	2-way	3-way	4-way		
Number of splitters	2	0	7		
Jumper types	0.3 m	1 m			
Number of jumpers	4	4			
Number of couplers	0				
Cable types	½"	⅞"	1¼"	1⅝"	
Cable length (m)	186.8	120	199.4	0	
Number of connectors	52	8	4	0	

TABLE 15

Details of the results of FIG. 11(b)					
Required BTS Power (dBm)	38.86				
Total cost ($)	6038.97				
Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	570	0	4486.77	884	98.2
Splitter types	3-way	4-way	5-way		
Number of splitters	1	0	6		
Jumper types	0.3 m	1 m			
Number of jumpers	4	2			
Number of couplers	0				
Cable types	½"	⅞"	1¼"	1⅝"	
Cable length (m)	255	44.7	239.4	0	
Number of connectors	60	2	4	0	

Tables 14 and 15 illustrate details of the results of FIG. **11**(*a*) and FIG. **11**(*b*) respectively. The required transmission power at all riser locations in multiple floors is satisfied. The total required BTS transmission power in both situations is around 38 dBm and there is not a large cost difference. The disadvantage of the tree topology in the vertical connection is that more parallel cables are installed in order to balance the power. Consequently, the total cost in the bus topology is much lower than that in the tree topology, which is opposite to the comparison between the two topologies in the horizontal connection described earlier.

FIG. **12**(*a*) and FIG. **12**(*b*) illustrate results of a vertical bus topology and a vertical hybrid topology respectively. In the hybrid topology, the splitters connected to the components in the risers are connected to the BTS by couplers. One-level cascade of splitters is used in the basic hybrid topology; meaning only one splitter is installed between the bus and the connection port in each floor.

TABLE 16

Details of the vertical bus topology of FIG. 12(a)		
Coupler No.	Coupler Type(dB)	Coupler Location
#1	20	(40, 7)
#2	20	(40, 12)
#3	20	(40, 17)
#4	20	(40, 22)
#5	20	(40, 27)
#6	20	(40, 32)
#7	20	(40, 37)
#8	20	(40, 42)
#9	20	(40, 47)
#10	20	(40, 52)
#11	20	(40, 57)
#12	20	(40, 62)
#13	20	(40, 67)
#14	20	(40, 72)
#15	15	(40, 77)
#16	15	(40, 82)
#17	15	(40, 87)
#18	15	(40, 92)
#19	15	(40, 97)
#20	15	(40, 102)
#21	10	(40, 107)
#22	10	(40, 112)
#23	10	(40, 117)
#24	10	(40, 122)
#25	10	(40, 127)
#26	10	(40, 132)
#27	6	(40, 137)
#28	6	(40, 142)
#29	3	(40, 147)
#30	0	(40, 152)
Required BTS Power (dBm)	46	
Total cost ($)	2861	
Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	0	1078	670	639	474
Splitter types	3-way	4-way			
Number of splitters	0	0			
Jumper types	0.3 m	1 m			
Number of jumpers	29	0			
Number of couplers	29				
Cable types	½"	⅞"	1¼"	1⅝"	
Cable length (m)	145	25	0	0	
Number of connectors	58	2	0	0	

TABLE 17

Details of the vertical bus topology of FIG. 12(b)		
Coupler No.	Coupler Type(dB)	Coupler Location
#1	15	(40, 11.7)
#2	15	(40, 31.7)
#3	15	(40, 51.7)
#4	10	(40, 76.7)
#5	10	(40, 91.7)
#6	6	(40, 111.7)
#7	3	(40, 131.7)
#8	0	(40, 146.7)
Required BTS Power (dBm)	47	
Total cost ($)	2912	

TABLE 17-continued

Details of the vertical bus topology of FIG. 12(b)					
Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	444	238	1314	657	230
Splitter types		2-way		4-way	
Number of splitters		1		7	
Jumper types		0.3 m		1 m	
Number of jumpers		11		4	
Number of couplers			29		
Cable types		½"	⅞"	1¼"	1⅝"
Cable length (m)		236.8	74.7	0	0
Number of connectors		54	6	0	0

Tables 16 and 17 provide details of these two types of topologies of FIG. **12**(*a*) and FIG. **12**(*b*) respectively, and it is shown that there is a small difference in the total required BTS transmission power.

FIG. **13**(*a*) and FIG. **13**(*b*) illustrate the tree topology with multi-level cascades of splitters and the basic hybrid topology combined. FIG. **13**(*a*) illustrates the hybrid topology with three couplers and two-level cascades of splitter connection, and FIG. **13**(*b*) illustrates the hybrid topology with four couplers and two-level cascades of splitter connection.

TABLE 18

Details of hybrid topology of FIG. 13(a)		
Coupler No.	Coupler Type(dB)	Coupler Location
#1	15	(40, 11.7)
#2	15	(40, 31.7)
#3	10	(40, 51.7)
Required BTS Power (dBm)	49	
Total cost ($)	3798	

Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	568	120	2171	790	212
Splitter types		2-way		4-way	
Number of splitters		1		7	
Jumper types		0.3 m		1 m	
Number of jumpers		4		2	
Number of couplers			3		
Cable types		½"	⅞"	1¼"	1⅝"
Cable length (m)		80.9	49.7	55	0
Number of connectors		20	4	2	0

TABLE 19

Details of the vertical bus topology of FIG. 13(b)		
Coupler No.	Coupler Type(dB)	Coupler Location
#1	15	(40, 11.7)
#2	10	(40, 31.7)
#3	10	(40, 51.7)
#4	6	(40, 71.7)
Required BTS Power (dBm)	45	
Total cost ($)	3166.7	

TABLE 19-continued

Details of the vertical bus topology of FIG. 13(b)					
Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	558	160	1516.5	720	212
Splitter types		2-way		4-way	
Number of splitters		1		7	
Jumper types		0.3 m		1 m	
Number of jumpers		6		2	
Number of couplers			4		

Tables 18 and 19 provide details of the hybrid topology of FIG. **13**(*a*) and FIG. **13**(*b*) respectively. Differences in the hybrid types can result in very different required total BTS transmission power and total cost.

FIG. **14**(*a*) illustrates the basic hybrid topology with two buses, and FIG. **14**(*b*) illustrates the basic hybrid topology with three buses.

TABLE 20

Details of basic hybrid topology of FIG. 14(a)		
Coupler No.	Coupler Type(dB)	Coupler Location
#1	6	(40, 86.7)
#2	6	(40, 111.7)
#3	3	(40, 131.7)
#4	10	(40, 11.7)
#5	6	(40, 31.7)
#6	3	(40, 51.7)
Required BTS Power (dBm)	42.8	
Total cost ($)	4635	

Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	482	196	2867	830	259
Splitter types		2-way	3-way	4-way	
Number of splitters		3	1	6	
Jumper types		0.3 m		1 m	
Number of jumpers		5		2	
Number of couplers			6		
Cable types		½"	⅞"	1¼"	1⅝"
Cable length (m)		111	50	0	0
Number of connectors		26	4	0	0

TABLE 21

Details of the basic hybrid topology of FIG. 14(b)		
Coupler No.	Coupler Type(dB)	Coupler Location
#1	6	(40, 11.7)
#2	3	(40, 31.7)
#3	6	(40, 66.7)
#4	3	(40, 81.7)
#5	6	(40, 111.7)
#6	3	(40, 131.7)
Required BTS Power (dBm)	42.7	
Total cost ($)	5804	

TABLE 21-continued

Details of the basic hybrid topology of FIG. 14(b)

Component types	Splitter	Coupler	Cable	Connector	Jumper
Component cost ($)	510	116	4057	830	291
Splitter types		2-way	3-way	4-way	
Number of splitters		3	1	6	
Jumper types			0.3 m	1 m	
Number of jumpers			3	2	
Number of couplers			6		
Cable types		½"	⅞"	1¼"	1⅝"
Cable length (m)		81	0	130	0
Number of connectors		18	0	2	0

Tables 20 and 21 provides details of the topology of FIG. **14**(*a*) and FIG. **14**(*b*) respectively. The topology with three buses uses more cable and results in a higher component cost, while the required BTS power is similar.

Cable Type Adjustment

The initial cable type selection is based on cable length between components, as described earlier. It may, however, be possible to include further power consumption efficiency by selecting a different cable size. For example, it is possible that the cable length between components is little and then many cables with small sizes are used. Consequently, more transmission power from the BTS is required due to the high power attenuation of ½" and ⅞" cables. If cost allows, thicker cables can replace the thinner cables starting from the BTS to save the power consumption.

FIG. **15** diagrammatically illustrates a method **1500** of adjusting the cable size, according to an embodiment of the present invention. Given four possible types of cable, namely ½", ⅞", 1¼" and 1⅝", and the total cables are

$$\{N_x\}_{x=1}^{X}$$

ranking with the ascending size.

In step **1505**, the method is initialized and the cables along the cable backbone (bus and hybrid topologies) are

$$\{N_x\}_{x=1}^{X}$$

ranked starting from the BTS. The cable size adjustment starts from the cable connected to the BTS.

At step **1510**, it is determined if the cable is the maximum cable size. If yes, the next cable is chosen for analysis in step **1515**. If no, the next cable size larger is tested in step **1520**.

In step **1525**, it is determined if costs allow for the new cable size. If not, the method is completed. If yes, the total required BTS transmission power is calculated in **1530**.

If the total required BTS transmission power still exceeds the maximum allowed transmission power, P_T, as described in step **1535**, it is checked if all cables are updated in step **1540**. Otherwise the method is concluded.

If not all cables have been updated, as determined in **1540**, the next cable size is chosen in step **1515**.

If all cables have the maximum size, as determined in step **1545**, the method from step **1510** is repeated from the first cable.

Reduce the Total Component Cost Further

The cable contributes much cost in the component placement. FIG. **16** describes a method of reducing the cost further.

At step **1605**, the method is initialised. Given that there are four cable sizes, ½", ⅞", 1¼" and 1⅝", the total cables are

$$\{N_y\}_{y=1}^{Y}$$

rank with the descending size. The cable size adjustment starts from the cable with the largest size, y=1.

At step **1610**, it is determined if the cable size is the minimum cable size. If yes, the next cable is selected in step **1615**. If no, the smaller cable size is chosen in step **1620**. At step **1630** antenna EIRPs are calculated. In step **1635**, it is determined if the EIRP meets the minimum EIRP requirements, and if so one lower level size will be tried until the updated minimum antenna EIRP exceeds the EIRP requirement exactly by repeating steps **1620**-**1635** if the lower level size is not the minimum size. If the minimum EIRP fails to satisfy the EIRP requirement, the cable size will be set to the previous size in step **1640**.

At step **1645**, it is determined if all the cable sizes have been updated. If no, the next cable is selected in step **1615**. If yes, the method is concluded.

Non-Placement Area Avoidance

In addition to choosing component types and locations according to the previously described methods, non-placement area avoidance can be considered. The non-placement area could be a polygon with any shape. FIG. **17***a* illustrates a convex shape and FIG. **17***b* illustrates a concave shape of a non-placement area.

At first, the available shifting directions are selected because some boundaries of non-placement area could coincide with the floor plan boundaries. Secondly, the distance from the component to each border of the polygon from all available directions can be calculated by Heron's formula and the direction with the minimum distance is chosen. Therefore, for the convex non-placement area avoidance, the component located at position **1705** will be moved to **1710** with a certain distance, e.g., 0 or 0.5 m, from the border L**1** along the perpendicular line to L**1**. If the non-placement area is a cylinder pillar area, the movement direction is from the component to the point on the circle nearest to the component. In addition, there is a special case that if the non-placement area is concave and the component A is placed close to the concave vertex B. In this case, the perpendicular line with the minimum length is the one from location **1705** to L**1**, but it doesn't have intersection point with L**1**. Consequently, the perpendicular direction to L**1** is unavailable. To move the component from position **1705** out of the area with some distance from boundaries, the updated location **1710** would be the final location which has the same distance to L**1** and L**2**.

Riser Location Selection

FIG. **18** illustrates a floor plan, including possible riser location options **1805**. For each possible riser location **1805**, several solutions with different topologies are generated using the methods **300**, **400** and/or **600** described earlier. Given design requirements, such as cost limitation and maximum utilization of BTS transmission power, all horizontal and vertical solutions based on different riser locations are generated and, referring to the desirable design target, the best or most suitable solution is chosen from these solutions.

System Upgrade and Adjustment

In terms of the service upgrade, such as the upgrade from 2G system to 3G or 4G, additional antennas will be installed

due to higher frequency bands and data rates to be supplied. In order to avoid many changes of the current cable installation, the methods described herein need not re-determine all designs based on all antennas, but can determine the additional component types and locations based on the existing design. The additional antennas which have the cable length less than L_{max} to the backbone will be connected by couplers. The coupler will also be used to connect the additional antenna if its number is only one. For those antennas, more than one, which have the cable length more than L_{max} to the backbone, the splitters with more output numbers could replace the current ones close to the additional antennas. More splitters are placed with the tree topology if the closest splitters already have the maximum output numbers.

FIG. **19** illustrates a system upgrade and adjustment solution according to an embodiment of the present invention. Five additional antennas **1905***a-e*, are placed, which are to be connected. Splitter **1910***i*, positioned close to antenna **1905***a*, is updated to be a 3-way splitter to connect the antenna **1905***a*. Similarly, antenna **1905***b* is connected to splitter **1910***j* by changing splitter **1910***j* from a 3-way splitter to a 4-way splitter. A new coupler, **1915***f*, is placed to connect antenna **1905***e* and new 2-way **1910***h* connects antenna **1905***c* and **1905***d*. Another new coupler **1915***g* is used to connect the splitter **1910***h*.

FIG. **20** diagrammatically illustrates a computer **2000**, according to an embodiment of the present invention.

The computer **2000** includes a central processor **2002**, a system memory **2004** and a system bus **2006** that couples various system components, including coupling the system memory **2004** to the central processor **2002**. The system bus **2006** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures. The structure of system memory **2004** is well known to those skilled in the art and may include a basic input/output system (BIOS) stored in a read only memory (ROM) and one or more program modules such as operating systems, application programs and program data stored in random access memory (RAM).

The computer **2000** may also include a variety of interface units and drives for reading and writing data. In particular, the computer **2000** includes a hard disk interface **2008** and a removable memory interface **2010**, respectively coupling a hard disk drive **2012** and a removable memory drive **2014** to the system bus **2006**. Examples of removable memory drives **2014** include magnetic disk drives and optical disk drives. The drives and their associated computer-readable media, such as a Digital Versatile Disc (DVD) **2016** provide non-volatile storage of computer readable instructions, data structures, program modules and other data for the computer system **2000**. A single hard disk drive **2012** and a single removable memory drive **2014** are shown for illustration purposes only and with the understanding that the computer **2000** may include several similar drives. Furthermore, the computer **2000** may include drives for interfacing with other types of computer readable media.

The computer **2000** may include additional interfaces for connecting devices to the system bus **2006**. FIG. **20** shows a universal serial bus (USB) interface **2018** which may be used to couple a device to the system bus **2006**. For example, an IEEE 1394 interface **2020** may be used to couple additional devices to the computer **2000**.

The computer **2000** can operate in a networked environment using logical connections to one or more remote computers or other devices, such as a computer, a router, a network personal computer, a peer device or other common network node, a wireless telephone or wireless personal digital assistant. The computer **2000** includes a network interface **2022** that couples the system bus **2006** to a local area network (LAN) **2024**. Networking environments are commonplace in offices, enterprise-wide computer networks and home computer systems.

A wide area network (WAN), such as the Internet, can also be accessed by the computer **2000**, for example via a modem unit connected to a serial port interface **2026** or via the LAN **2024**.

It will be appreciated that the network connections shown and described are exemplary and other ways of establishing a communications link between the computers can be used. The existence of any of various well-known protocols, such as TCP/IP, Frame Relay, Ethernet, FTP, HTTP and the like, is presumed, and the computer **2000** can be operated in a client-server configuration to permit a user to retrieve web pages from a web server. Furthermore, any of various conventional web browsers can be used to display and manipulate data on web pages.

The operation of the computer **2000** can be controlled by a variety of different program modules. Examples of program modules are routines, programs, objects, components, and data structures that perform particular tasks or implement particular abstract data types. The present invention may also be practiced with other computer system configurations, including hand-held devices, multiprocessor systems, microprocessor-based or programmable consumer electronics, network PCS, minicomputers, mainframe computers, personal digital assistants and the like. Furthermore, the invention may also be practiced in distributed computing environments where tasks are performed by remote processing devices that are linked through a communications network. In a distributed computing environment, program modules may be located in both local and remote memory storage devices.

FIG. **21** describes the determination of component types and locations in a hybrid topology. In the initialization, the total number of buses should be defined. The maximum number of couplers used could determine the basic hybrid or combined hybrid topology because basic hybrid uses more couplers. The required power at end points will be used to determine the coupler types in a feedback algorithm discussed in FIG. **6**.

The method described for tree topology is used to determine the splitter types and locations.

For hybrid topology, fewer couplers but more splitters are used, which consist of multi-level cascade connections of splitters.

In order to increase the power consumption efficiency or reduce the total cost further, cable types are adjusted further as shown in FIG. **15** and FIG. **16**.

In summary, advantages of some embodiments of the present invention include guaranteeing the requirements of installed antennas, transmission power or financial budget. Network upgrade is simplified. These capabilities provide a user with a powerful and flexible design environment for wireless networks, which allows users to quickly and easily achieve optimal solutions with lowest cost for designing multiple service coverage areas according to different defined requirements.

The above description of various embodiments of the present invention is provided for purposes of description to one of ordinary skill in the related art. It is not intended to be exhaustive or to limit the invention to a single disclosed embodiment. As mentioned above, numerous alternatives and variations to the present invention will be apparent to those skilled in the art of the above teaching. Accordingly, while

some alternative embodiments have been discussed specifically, other embodiments will be apparent or relatively easily developed by those of ordinary skill in the art. Accordingly, this patent specification is intended to embrace all alternatives, modifications and variations of the present invention that have been discussed herein, and other embodiments that fall within the spirit and scope of the above described invention.

The invention claimed is:

1. A computer implemented method of determining component types and locations in a network design, the method including:

a. determining, by a computer processor, the component types and locations according to a riser location as an entry point and antenna locations as a plurality of end points, in a floor plan;

b. determining, by a computer processor, the minimum required transmission power at a riser location to meet antenna equivalent isotropically radiated power (EIRP) requirements in a floor plan;

c. determining, by a computer processor, the best riser location from available riser locations according to cost limitation or power transmission efficiency in a floor plan;

d. determining, by a computer processor, the component types and locations according to a Base Transceiver Station (BTS) location as an entry point and riser locations in different floors as a plurality of end points, in a building plan;

e. determining, by a computer processor, the minimum required BTS transmission power to meet said minimum required transmission power at each riser location calculated;

f. updating, by a computer processor, the component locations based upon areas specified as component non-placement area;

g. determining, by a computer processor, the initial types of cables according to the lengths of each cable;

h. adjusting, by a computer processor, sizes of some cables to increase power transmission efficiency from a BTS to antennas if the total cost budget allows;

i. adjusting, by a computer processor, the sizes of some cables to reduce the cable cost with the satisfaction of the antenna EIRP requirement;

j. determining, by a computer processor, types and locations of new components, and updating, by a computer processor, existing component types, according to the locations of new antennas for the system to be enhanced or upgraded to accept a new technology.

2. A method according to claim **1**, wherein the computer implemented method of determining component types and locations according to an entry point and a plurality of end points in a floor plan or in a building plan include,

a. determining the number, types and locations of splitters and cable types according to an entry point and a plurality of end points, in a tree topology;

b. determining the number, types and locations of couplers and cable types according to an entry point and a plurality of end points, in a bus topology;

c. determining the number, types and locations of splitters, couplers and cable types according to an entry point and a plurality of end points, in a hybrid topology;

d. determining the minimum required transmission power at an entry point according to the minimum required power at each end point in a tree, bus or hybrid topology.

3. A method according to claim **2**, wherein the option to choose tree, bus or hybrid topology in a floor plan or a building plan is determined based upon the floor plan, building plan, product availability, or by any other suitable means.

4. A method according to claim **2**, wherein the steps of determining the number, types and locations of splitters in a tree topology to a plurality of end points, which may be antenna locations, and an entry point, which may be a riser location, include,

a. determining the number, types and locations of a first set of splitters, wherein each end point is connected to one splitter of the first set of splitters;

b. determining iteratively the number, types and locations of any subsequent sets of splitters wherein each splitter in the set of splitters from the previous iteration is connected to one splitter of the new set of splitters; and

c. determining the type and locations of one final splitter wherein each remaining unconnected splitter from the first set of splitters or any subsequent set of splitters is connected to the final splitter and the entry point is connected to the final splitter.

5. A method according to claim **4**, wherein the steps of determining the number, types and locations of splitters to be connected to a plurality of end points as at least part of a tree topology include,

a. defining types of available splitters by deciding the maximum number of outputs of splitters;

b. determining number and types of splitters from available types of splitters based at least partly on the number of a plurality of end points and the remainder relationship between the number of splitter outputs and the number of end points;

c. determining a group including one or two splitters, the number of outputs of each splitter which is smaller than the predefined number of maximum number of outputs;

d. determining the locations of splitters in said group based at least partly on the locations of the plurality of end points to be connected and the cable length;

e. determining the locations of the remaining splitters based at least partly on the lengths of cables and the locations of the plurality of end points to be connected.

6. A method according to claim **5**, wherein the maximum number of outputs of splitters may be determined based on product availability, or by any other suitable means.

7. A method according to claim **4** or **5**, wherein the minimum required transmission power at a riser location, is calculated based upon the required transmission power at antennas, the power loss of cables and the insertion loss of splitters.

8. A method according to claim **4**, wherein the steps of determining types of splitters to be connected to splitters connected to a plurality of end points in a tree topology include, a. determining the number, types and locations of one or more further sets of splitters based on computer executable instructions for performing the method of claim **4** according to the number of pre-existing splitters as the end points;

b. determining the type and location of the last splitter to be connected to an entry point, then all end points are connected to the said last splitter via one or more further set of splitters.

9. A method according to claim **2**, wherein the steps of determining the number, types and locations of couplers in a bus topology with a plurality of end points, which may be antenna locations, and an entry point, which may be a riser location, include,

a. defining the number and orientation of buses, which are cable backbones;

b. grouping the end points according to said number and orientation of buses based upon the distance from each end point to the bus;

c. determining the locations of buses according to the locations of the end points in said respective groups;

d. determining the locations of couplers along the cable backbones according to said end points to be connected by couplers;

e. determining the types of couplers to be connected to said end points from available types of couplers based on the required transmission power at end points.

10. A method according to claim **9**, wherein the options of the number and orientation of buses in a floor plan or a building plan are determined based upon the floor plan, building plan, product availability, or by any other suitable means.

11. A method according to claim **9**, wherein the steps of determining the types of said couplers includes,

a. determining the types of couplers by the order from the coupler closest to the entry point to the coupler closest to end points;

b. searching the type of each coupler from available coupler types to just meet the minimum power requirement at each end point according to the power level at the entry point;

c. updating the types of couplers to balance the power allocated at each end point by increasing the minimum power requirement at each end point.

12. A method according to claim **11**, wherein the power level at the entry point is initialized in the start stage and then updated according to the available coupler types and minimum power requirements at end points.

13. A method according to claim **11**, wherein the power at each end point is calculated based upon the coupling loss and direct loss of each coupler.

14. A method according to claim **2**, wherein the steps of determining the number, types and locations of splitters and couplers in a hybrid topology with a plurality of end points, which may be antenna locations, and an entry point, which may be a riser location, include, a. defining the maximum cable length, which is a threshold, from the end points to the bus(es) to determine the end points to be connected by couplers, and the end points to be connected by splitters;

b. connecting the end point that have a cable length less than a threshold directly to the bus(es) via couplers;

c. determining the types and locations of couplers;

d. connecting the remaining end points to the bus(es) via splitters;

e. determining the types and locations of splitters;

f. connecting the splitters to the bus(es) via couplers.

15. A method according to claim **14**, wherein the said maximum cable length is defined based upon the floor plan, building plan, product availability, or by any other suitable means.

16. A method according to claim **14**, wherein the end points to be connected by splitters and couplers respectively can also be determined according to the cable length from the entry point to end points.

17. A method according to claim **2**, wherein the minimum requirement transmission power at the entry point is calculated based on the required power at the end points.

18. A method according to claim **1**, wherein the best riser location could be different in the tree, bus and hybrid networks as there may be no single best location for all three topologies.

19. A method according to claim **1**, wherein some cables are selected to be adjusted in size by searching all cables in the network and verifying total cost budget or required transmission at the entry point and end points.

20. A method according to claim **1**, wherein the steps of determining the number, types and locations of splitters and couplers to be added to an existing network design and connected to a plurality of new or existing end points, which may be antenna locations, when the system is enhanced or upgraded to accept a new technology, include

a. determining the types and locations of new couplers according to the end points to be connected by couplers if the end points have cable length less than the maximum cable length, which is a threshold, to the backbone;

b. determining the types and locations for the replacement of existing splitters with higher output numbers according to requirements of new and/or existing end points if the end points have cable length more than the maximum cable length, which is a threshold, to the backbone; and

c. determining the types and locations of new splitters to connect to the end points if the closest splitters already have the maximum number of outputs.

21. A method according to claim **20**, wherein required transmission power at the entry point is re-calculated in cases of network design for system upgrade and enhancement.

22. A method according to any one of the preceding claims, wherein a set of solutions to connect an entry point to a plurality of end points is derived, the best solution from them can be chosen according to the specific requirements from design specification, building environments determined by floor plans and building plans, limitation of transmission power, cost budget, etc.

23. The method of claim **1** further including:

a. determining that an endpoint of the plurality of endpoints has a transmission power difference with the required transmission of the endpoint greater than a threshold;

b. increasing the required transmission power for each of the endpoints of the plurality of endpoints by a predetermined increment;

c. determining the component types and locations are based upon at least the increased transmission power requirements.

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